A System Dynamics Approach to Supplier Partnership Management in Supply Chain

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Abstract

To be competitive and quick-to-market in today's global marketplace, Electronic Manufacturing Service (EMS) providers should focus on their core competencies, partnership relationships and continuous improvements. As Original Equipment Manufacturers (OEMs) Customers shift their focus on marketing and product development, EMS providers have been assuming the leading role to develop creative manufacturing solutions based on the core competencies in their supply chains. A tightly-coupled and synergistic relationship with OEM customers and key components suppliers is critical to EMS providers' success.

This thesis focuses on applying system dynamics approach to supplier partnership management at FSJC, a top player in EMS industry, with the aim of gain deeper understanding on dynamics within FSJC's supply chain network and between suppliers and FSJC. We find out that to maintain its market position, FSJC must concentrate on small number of qualified suppliers and put effort to build strong partnership with these suppliers. This requires a better understanding of the impact of key parameters of partnership and manufacturing process of both suppliers and FSJC.

Developing this sort of understanding can help FSJC continue to provide worldwide responsiveness to its customers by improving time-to-market, scalability and manufacturing efficiency and foster long-term partnership with both customers and suppliers by improving communications both upstream and downstream in the supply chain.

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Chapter 1 Introduction

1.1 EMS Industry Overview

1.1.1 Evolution of the Electronics Manufacturing Service industry

Electronics Manufacturing Services, formerly known as Contract manufacturers (CM) industry can trace its roots back to the early 1960's, when large electronics Original Equipment Manufacturers (OEMs) used outsourcing as a quick and cost effective means to deal with demand spikes without investing in capital and labor forces. As the EMS industry grew and invested heavily in manufacturing technology and equipment, EMS providers have been developing manufacturing competency that became difficult for traditional OEMs to match in terms of flexibility, technology leadership and cost. Furthermore, the purchasing power of the EMS providers grew considerably, allowing significant material cost reductions. During the late 1970's through 1990's, driven by accelerated outsourcing trend, most of the major players in the EMS industry operate with a global network and provide a full range of manufacturing services including circuit board design and layout, pre-production and prototype, material procurement and management, board, subsystem and system assembly, test, and shipment to the end user. In the world of electronics manufacturing, huge demand in product innovation was created by the high tech boom of the '90s, and forced the OEMs to be more responsive to deliver more advanced products in much shorter product life cycles. In order to focus on product innovation and marketing, OEMs increasingly turned to EMS providers to outsourcing some or all of their manufacturing and assembly operations. The expanding production and supply chain services that EMS providers subsequently facilitated the emergence and growth of OEM companies with 100% outsourced manufacturing models.

However, with the crash of technology and Internet sectors, the market turned in late 2000 and early 2001. OEMs cut off orders to EMS providers, and EMS providers did the same to their suppliers. Thus inventory piled up, expansion and growth strategies were put on hold, and capacity was underutilized throughout the supply chain. The recession has strained relationships between EMS providers and their OEM customers who have cancelled and pushed back orders in response to weak market demand. Under such circumstances, EMS Providers must maintain their long-term goal to provide supply chain services balancing the security and unique requirements of OEM customers. With enhanced role of becoming more responsible for cost reduction and supply chain efficiency, EMS providers are focusing on their core competencies, partner relationship and continuous improvement.

1.1.2 Critical Issues for EMS Providers to Build Successful Supply Chain Models

As OEMs continue to outsource the manufacturing and assembly operations, EMS providers inherit more and more responsibility for supply chain functions that many OEMs spent years trying to optimize internally. Long term success of the outsourcing supply chain model depends on whether EMS providers can maintain and improve supply chain efficiencies. There are several factors that are critical for EMS providers to build a successful model for the future.

1. Focus on integrating operations from merger and acquisition

Many EMS providers are facing the challenge of integrating operations from merger and new acquisitions purchased from OEM customers. Each plant comes with its own infrastructure, processes, people, systems and data. The management challenge of integrating these operations can be categorized into Plant operations, Supply chain optimization, and Information systems integration.

2. Promote communication and trust between OEMs and EMS providers, and EMS providers and key suppliers

OEMs, EMS providers and key suppliers need to work on improving communication, sharing information, and understanding each others' strengths and weaknesses. Although OEM customers outsource more and more functions, including design services, component sourcing, and logistics and supply chain support, to EMS providers, discrepancy does exist between what OEMs think about the services offered by their EMS providers and how EMS providers view themselves. Furthermore, information sharing still needs improvement among the three parties.

3. Integrating supply chain technology to enable collaboration

The EMS industry is leading the pack in the need for integrating supply chain systems and operations to achieve collaboration. Now technology can truly support these collaborative partnerships allowing organizations to realize tangible and visible results by integrating supply chain technologies.

1.2 Vertical versus Virtual Integration EMS Business Model

Two different business models exist in the EMS industry, vertical integration model and virtual integration model. Companies that choose the vertically integrated business model directly own the suppliers capacity and produce multiple value-adding stages from raw material to the sale of products to customers. Owning and coordinating the supplier capacity allow these vertically integrated EMS providers to offer greater operating leverage, especially when the demand for supplier capacity is huge. While certain benefits can be realized through vertical integration, this asset-based method of organizing supplier capacity has some drawbacks. First, owning everything, particularly those components that are dissimilar to the core competency, could place a significant burden on a company's financial position. A second drawback to this model of vertical integration is that the creation of one large entity may make it less responsive to the unpredictable downturn of the market.

The virtual integration model is similar to the vertical integration model in the sense that it attempts to link the suppliers into an integrated system to operate like a single entity. Virtual integration emphasizes coordination and strategic alliance with suppliers through cost-sharing and risk-sharing agreements. The biggest attraction of virtual integration is that EMS providers can achieve reduced cost, improved quality and increased market share without investing huge amounts of capital or completely altering their structures. Thus virtual EMS business models provide more downside protection. However, EMS providers that choose the virtually integrated models would face the possible supplier capacity shortage when market expands dramatically and there is huge demand for raw material allocation.

1.3 System Dynamics

1.3.1 System Dynamics Overview

Founded at MIT Sloan in 1956 by Professor Jay W. Forrester, system dynamics is a powerful methodology combining the theory, methods, and philosophy needed to analyze business policy and decision making. System dynamic provides a unique framework for diagnosing the root causes of strategic business problems. In particular, causal loop diagrams and simulation models make it possible to capture the essential interactions of a sophisticated business system.

1.3.2 System Dynamics Standard Method

Although there is no universally accepted process for developing good quality system dynamics models, most system dynamics practitioners follow a sequence of steps roughly in line with the "standard method"[1]. The steps are:

1. Problem definition

   1) List of variables.

   Identify some key quantities that will need to be included in the model to address the issues at hand. Variables are things that can go up, can go down or can stay the same. All the variables have a bearing on what the clients already know the issue to be. It can sometimes be useful just to write down all of the variables that might be important and then ask the clients to identify the most important six key variables.

   2) Reference modes

   Reference modes are drawn as graphs over time for the pattern of key variables. The graphs show how the concern evolves from the past into their current state and then what the clients' hopes and fears are going forward. Most dynamic behavior are examples of a small set of basic patterns of behavior, exponential growth, goal seeking, and oscillation. By plotting the dynamics of the six key variables, we are able to capture the most representative behavior patterns.

   3) Problem statement

[1] See Jim Hines, The "Standard Method", 2003

The problem statement is simply a statement that makes it clear the clients concerns and the purpose of the model. One or two of the reference modes almost certainly will contain a true major concern of the clients.

2. Momentum policies

A momentum policy is a solution that the clients would implement today if they have to make a decision immediately without further time to collect information or ponder. The momentum policy could be a policy the clients have already implemented or one that will be implemented in the future.

3. Dynamic hypotheses (i.e. causal loop diagrams)

A dynamic hypothesis a theory about what structure exists that generates the reference modes, that is, the potential explanations for the patter of behavior in the reference modes.

4. Model the first loop

A simulation model is the refinement of a set of dynamic hypotheses to an explicit set of models in terms of flows and stocks. Simulation models generate behavior through simulation.

5. Analyze the first loop
6. Model the second loop
7. Analyze the second loop
8. Model the n^{th} loop
9. Analyze the n^{th} loop
10. Insights and recommended strategies.

System dynamics modeling is an iterative and feedback process. Insights and conclusions may surprisingly emerge at any step during the process and lead to revisions in any earlier step. To describe the system dynamics approach in more detail, we will work through these steps based on the project we conducted with a senior management team at FSJC, one of top players in the EMS industry. To respect the company's request for anonymity, we use the pseudonym FSJC instead of the company's real name within the scope of this thesis.

1.4 Thesis Overview

To gain deep insights into supplier partnership management at FSJC, a top tier EMS provider with a virtual integration business model, we worked with a senior management team at FSJC and applied the standard system dynamics method to understanding the partnership between FSJC and its suppliers. The thesis is structured as follows:

Chapter 1 reviews the evolvement of Electronic Manufacturing Service (EMS) industry, two different EMS business models, and system dynamics methodology.

Chapter 2 discusses the problem statement in terms of list of variables and reference modes which capture FSCG team's real concerns and addresses the momentum policies.

Chapter 3 describes the dynamics hypotheses in term of causal loop diagrams focusing on the cause and effect relationship between FSJC and its suppliers.

Chapter 4 converts the central causal loop to the system dynamics model which presents the working partnership between FSJC and its suppliers.

Chapter 5 analyzes the dynamic behavior of the model through different scenarios of simulation.

Chapter 6 summarizes the insights throughout the project and recommends strategies based on analysis of the model.

Chapter 2 Problem Statement

FSJC, one of the top players in the EMS industry, operates a highly sophisticated global manufacturing network with operations in Asia, Europe and the Americas, providing a broad range of services to leading original equipment manufacturers (OEMs) across a variety of industries. As a recognized leader in quality, technology and supply chain management, FSJC provides competitive advantage to its customers by improving time-to-market, scalability and manufacturing efficiency.

However, FSJC is concerned about whether it can get sufficient capacity allocation from suppliers when the market recovers and market demands increase dramatically. Contrary to most of its competitors, who have the vertical integration models and directly own the suppliers capacity, FSJC has been building a virtually integration model to manage its supplier capacity. Furthermore, FSJC wants to work with a small number of suppliers on the strategic level, which will provide FSJC the same level of control over the suppliers as its competitors, without actually owning the suppliers capacity. However, the challenge is that FSJC has very limited insight into suppliers' operations and their flexibility to meet unpredictable demands.

2.1 List of Variables

The initial step of the standard system dynamics approach is to identify the key variables important to the problem as a first step toward clarifying the issues at hand. We conducted interviews with senior managers and identified over 60 variables in seven categories including, partnership between FSJC and suppliers, FSJC's attractiveness, supplier capacity availability, lead time, supplier capability, finance, and suppliers' ability to manage supply chain organizations. From the list of variables, the FSJC team chose six most important variables.

1. Priority of FSJC on supplier's customer list
2. Gap between desired capacity and actual capacity from suppliers
3. Flexibility of suppliers allocating raw material for FSJC
4. number of suppliers that FSJC can choose from

5. Leverage of suppliers to purchase raw material
6. percentage of FSJC's qualified suppliers

2.2 Reference Modes

As system dynamics modelers, we seek to characterize the problem dynamically as patterns of behavior over time. Reference modes are drawn as a set of graphs over time showing how the clients' concerns evolve from the past into their current state and then what the clients' hopes and fears are going forward.

1. Priority of FSJC on supplier's customer list

The priority of FSJC on supplier's customer list is mainly measured by the percentage of FSJC 's capacity demand contributing to suppliers' total revenue. Driven by FSJC's reputation in the EMS industry, its priority on suppliers' customer list has been increasing gradually over time. FSJC hope that the priority will continue to go up and fear that it will go down in the future. However, there is some limitation for the growth of the priority since suppliers want to diversify their customer base.

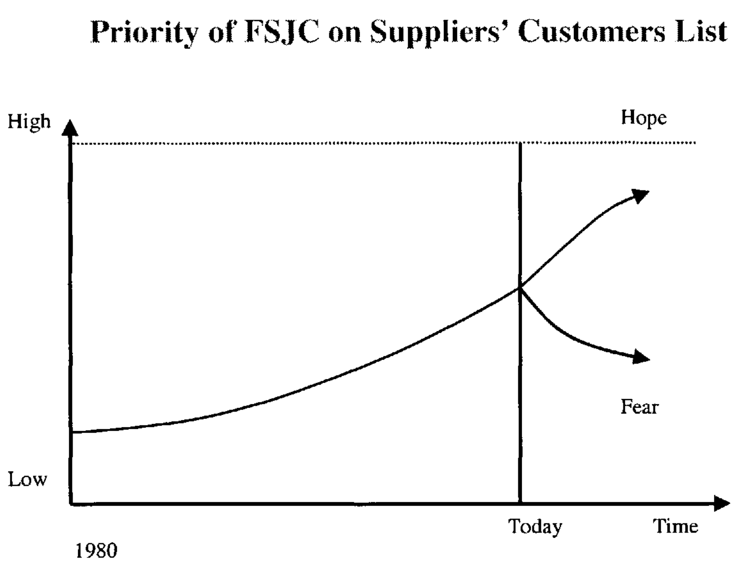

Figure 2-1 Reference mode 1: Priority

2. Gap between the desired supplier capacity and actual supplier capacity

The gap between the desired supplier capacity and actual supplier capacity tends to fluctuate according to market demand and exhibits cyclical oscillations. In general, when there is surplus supplier capacity, the gap goes down. When there is shortage of capacity, everyone is competing for supplier capacity and the capacity gap picks up. Over the last several years, the gap between the desired capacity and actual capacity has been narrowing down. FSJC hopes that the capacity gap can continue to go down and fears that the capacity gap will increase in the future. Clearly, since the market demand involves unavoidable fluctuation, the future trend of capacity gap will also exhibit the small cyclical fluctuation.

Gap between desired capacity and actual capacity from suppliers

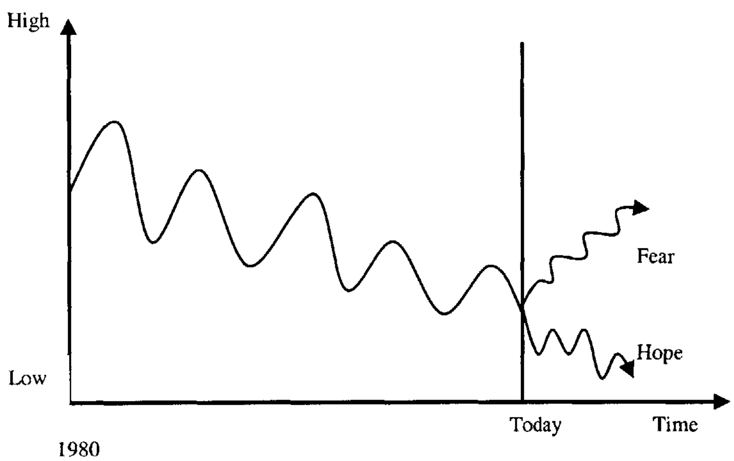

Figure 2-2 Reference mode 2: Supplier Capacity Gap

3. Suppliers' Flexibility to allocate raw material for FSJC

The flexibility of suppliers to allocate raw material for FSJC has been increasing gradually over time. The stronger the relationship between FSJC and the suppliers, the more flexibility the suppliers can provide in terms of carrying and allocating raw material for FSJC. The flexibility that FSJC can provide to customers depends largely on the flexibility that FSJC can get from suppliers. FSJC hopes that the supplier's flexibility to allocate raw material will continue the increased trend and fears decreased flexibility of raw material allocation from suppliers.

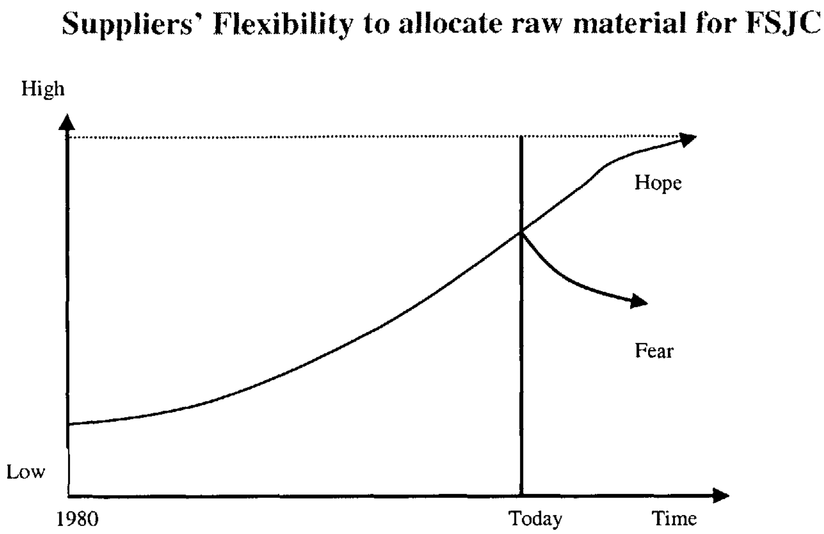

Figure 2-3 Reference Mode 3: Suppliers' Flexibility to Allocate Raw Material for FSJC

4. Total number of suppliers FSJC can choose from

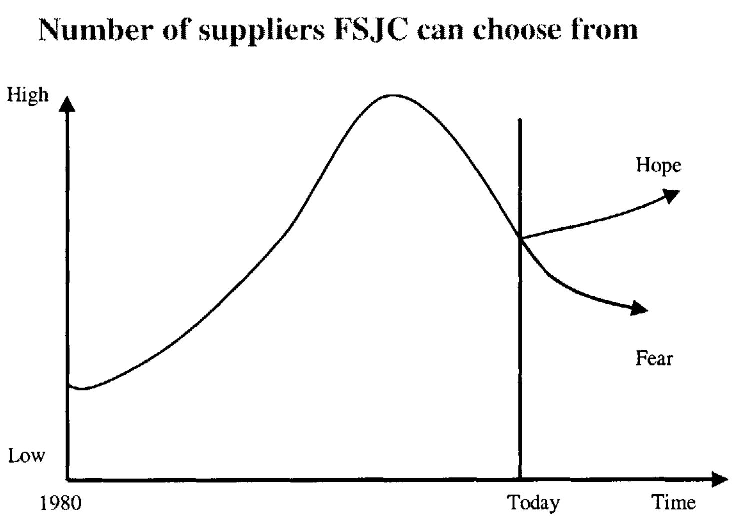

Figure 2-4 Reference mode 4: Number of Suppliers FSJC can choose from

The total number of suppliers that FSJC can choose from is a subset of all suppliers for the entire EMS industry. The behavior pattern of the number of suppliers FSJC can choose evolves similarly to the total number of suppliers in the EMS industry. This total number of suppliers increased gradually and reached highest around 2000. All the suppliers were expanding and opening new facilities world wide. However, with the crush of telecom bubble at the end of 2000, suppliers in North America and Europe began to close some of the facilities. FSJC hopes the number of suppliers to increase to a level a little bit lower than the peak in three to five years and fears that the number will continue to go down.

5. Leverage of suppliers to purchase raw material

The leverage of suppliers to purchase raw material is evaluated based on suppliers' credit, records of suppliers, suppliers' market share and reputation. By increasing market share and reputation, FSJC attract more suppliers that are willing to build mutual relationship and grow together with FSJC. Over years, the unpredictable demand has been driving the supplier to get the raw material more quickly. The more leverage that suppliers have to purchase raw material, the more business FSJC will bring the suppliers. FSJC hopes that the suppliers' leverage to purchase the raw material will continue to increase and fears that it will go down in the future.

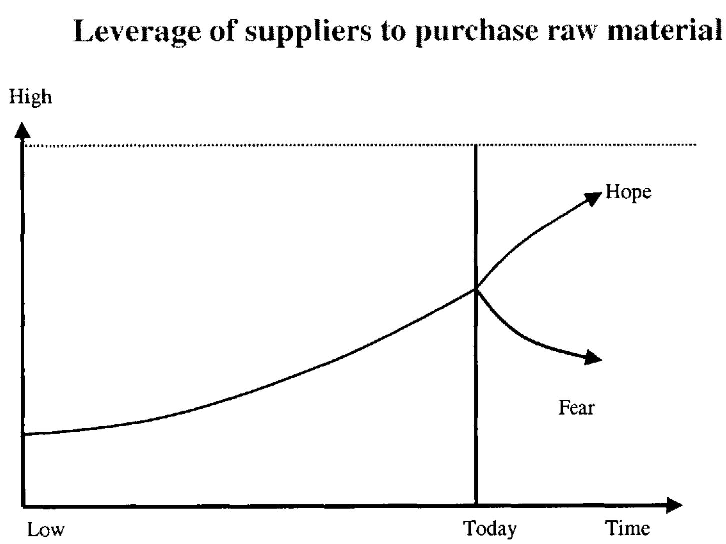

Figure 2-5 Reference mode 5: leverage of Suppliers to Purchase Raw Material

6. Percentage of qualified suppliers

Basically, there are three categories of suppliers within FSJC's supplier base, that is, qualified suppliers, preferred suppliers and other suppliers. From the total supplier base, FSJC chooses a certain percentage of the total suppliers as preferred suppliers. From those preferred suppliers, FSJC chooses certain number of suppliers to be the qualified suppliers, with whom

FSJC hopes to build long term strategic partnership. The percentage of qualified suppliers follows the similar pattern of the total number of suppliers FSJC can choose from. As the total number of suppliers went down, the number of FSJC's qualified suppliers gone down too. However, in the long term, FSJC wants to reduce the supply base and work with a small number of qualified suppliers. FSJC hopes the percentage of qualified suppliers will increase and fears that the percentage of qualified suppliers will go down.

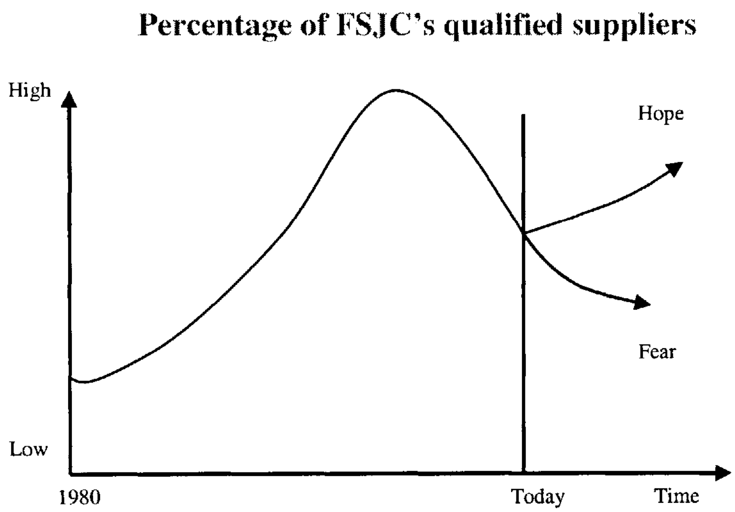

Figure 2-6 Reference Mode 6: percentage of qualified suppliers

2.3 Problem Statement

The purpose of the modeling is to help the clients solve the problems shown in reference modes 1 and 2 (See figure 2-1 and figure 2-2). The FSJC team agreed that there are two variables that capture their major concerns regarding to supplier capacity issue:

(1) Priority of FSJC on supplier's customer list

(2) Gap between desired capacity and actual capacity from suppliers

The problems can be formulated as follows,

How FSJC can increase the priority on suppliers' customer list and reduce the gap between desired capacity and actual capacity when the market demand increases dramatically?

2.4 Momentum Policies

After clarifying what the real problems are, we work with FSJC team to generate the momentum policies, which are current policies or potential solutions to problems at hand without further collecting information and pondering. The momentum policies collected are formulated as follows:

1. Early involvement of suppliers, FSJC, and OEM customers in the new product development.

As FSJC's customers concentrate on marketing and new product development, in order to better meet the customers' requirements for innovation, it is important for FSJC to bring suppliers earlier into the design process of new product introduction. In this way, FSJC can help suppliers to better prepare for the future usage of raw material. Currently, FSJC tries to involve the suppliers in the new product development as early as possible.

2. More certainty about demand in terms of commitment to customers' demand and reserved capacity to suppliers.

Based on the forecast, FSJC releases the purchasing orders to suppliers to replenish the components and raw material, manufacture them, and build up the Work in Process inventory. FSJC do the final assembly and test according to actual customer orders. Through contracts, FSJC reserves capacity with suppliers. FSJC is faced with two major challenges: (1) FSJC cannot 100% sure about the required supplier capacity to meet customers demand and (2) FSJC needs to have enough supplier capacity for its commitment to customers demand. FSJC hopes to gain high visibility to demands from customers and at the same time increase suppliers' visibility to the raw material usage.

3. Increase FSJC 's priority on suppliers' customer list

Since FSJC does not directly own the suppliers' capacity, it is essential that FSJC can maintain and improve its priority on suppliers' customer list, especially when demand shoots up and competitors are competing for supplier capacity. By bring more business to the suppliers, FSJC can increase the priority on suppliers' customer list and gain more flexibility on raw material allocation.

4. Reduce the supplier base and build strong partnership with qualified suppliers.

Currently, FSJC has a huge supplier base and works with around 3,000 to 4,000 suppliers worldwide. By consolidating demand and concentrating on a small number of qualified suppliers, FSJC will be able to build a long term strategic partnership with the qualified suppliers.

5. Share more risk with suppliers by investing in tooling and raw material inventory.

The key to a successful partnership in a virtual integration business model is to identify the areas that can reduce risk and uncertainty throughout the supply chain. Through investments in specialized tooling and raw material inventory, FSJC can share more risk with suppliers and also gain more flexibility on raw material allocation.

6. Provide better service to the current customer base and attract more tier-1 customers.

The customers will not outsource more responsibility to FSJC unless they have more trust in FSJC. By improving the service to the customers, FSJC can gain more trust from OEM customers. By taking more responsibility and attracting more tier-1 customers, FSJC can increase its attractiveness to the suppliers. Thus, FSJC can gain more respect from suppliers.

7. Grow with small entry-level startup companies. Provide more service and commodity management to help the growth of these small companies.

Chapter 3 Dynamic Hypotheses

Once the problem has been identified, we can begin to develop the dynamic hypotheses which provide the explanations of the dynamics characterizing the problem in terms of the underlying feedback structure of the system. System dynamics seeks endogenous explanations for phenomena since the behavior of a system arises from its structure. By specifying how the system is structured and decision rules of the system, we can explore how the patterns of behavior are created by those rules and the structure and how the behavior might change if we alter the structure and decisions. We formulated the dynamics hypotheses in terms of causal loop diagrams that correspond to the explanations that are responsible for the behavior patterns in the reference modes discussed in chapter 2.

3.1 Dynamic Hypothesis 1: The higher the priority, the smaller the capacity gap

Driven by FSJC's reputation and market share in the EMS industry, more and more suppliers are willing to work with FSJC. By attracting increased demand from customers, FSJC can generate more capacity demand for the suppliers. By bring more business to the suppliers, FSJC will improve the priority on suppliers' customer list and grow together with the suppliers.

By increasing the market share in the EMS industry and carrying more responsibility from OEM customers, FSJC can increase the priority on suppliers' customer list and thus increase the capacity that FSJC get from the suppliers and further increase the customer satisfaction and FSJC's market share. Also the competition in the EMS industry also contributes to the oscillation of the gap since everyone has been fighting the capacity in the EMS industry. The more availability of suppliers' capacity is, the less the supplier capacity gap is.

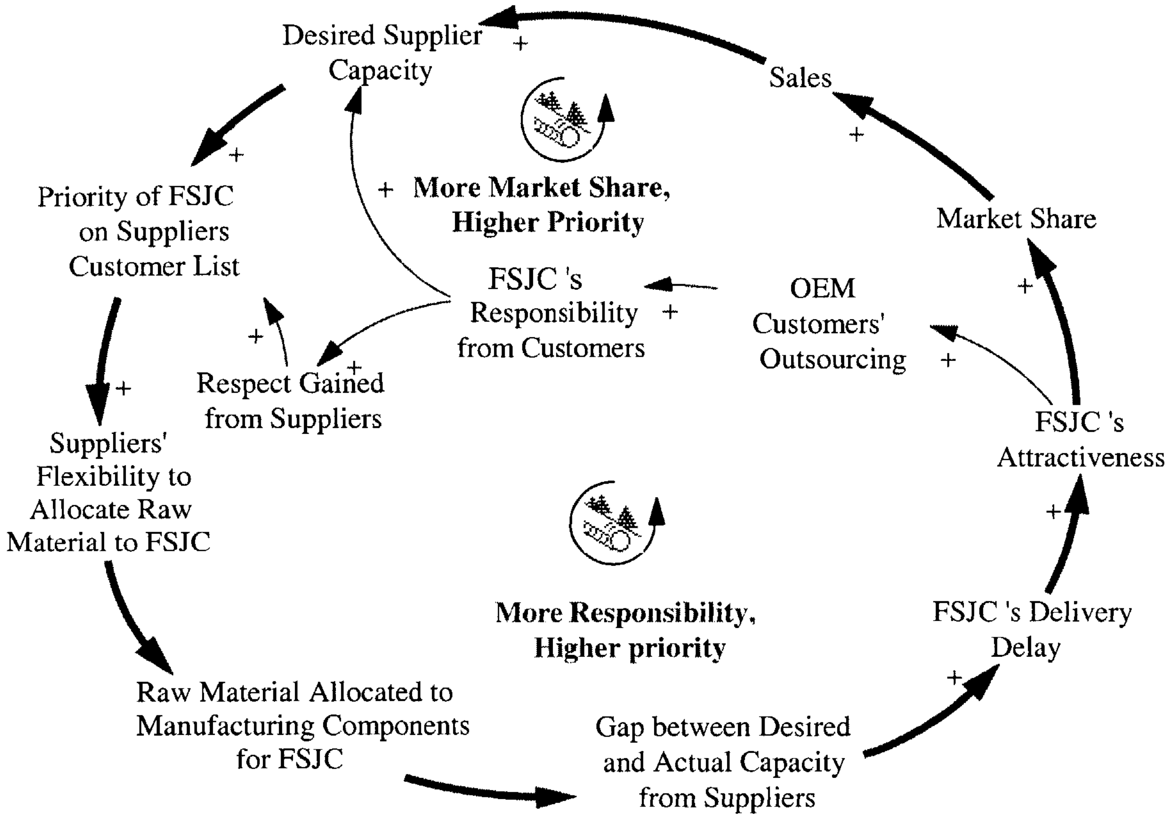

Figure 3-1 Dynamic Hypothesis 1: Priority

3.2 Dynamic hypothesis 2: Attract more tier-1 customers

By providing more competitive service to the current customers and attracting more demand from customers, especially the tier 1 customers, FSJC will be able to maintain a top-tier player in the EMS industry and continue to carry more responsibility for the customers. By gaining more business from customers, FSJC can offer more business to suppliers, which will encourage suppliers to expand their capacity when market picks up.

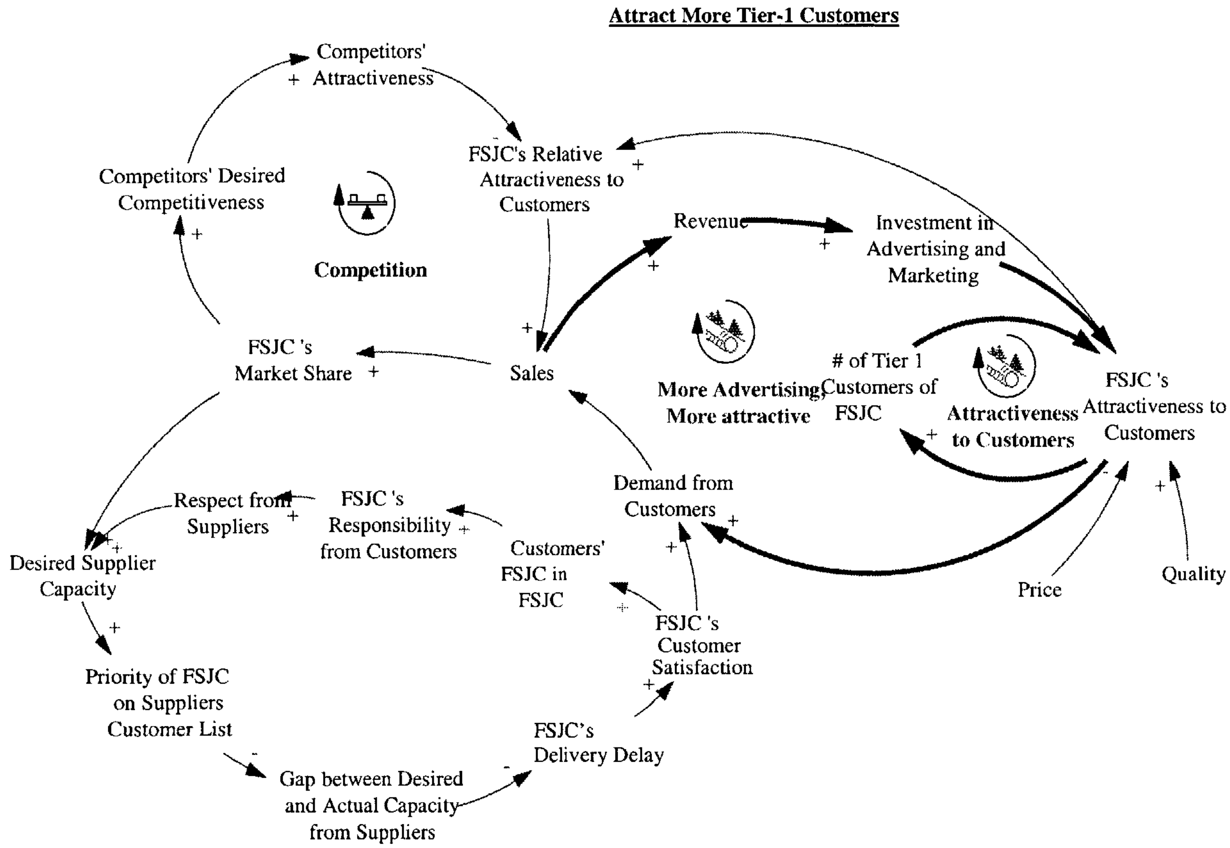

Figure 3-2 Dynamics Hypothesis 2, Tier 1 customers

3.3 Dynamic Hypothesis 3: Increase flexibility

The increasing suppliers' flexibility to allocate raw material for FSJC has been driven by several factors, including suppliers' ability to manage unpredictable demand, priority of FSJC on suppliers' customer list, shared risk, and shared information. By increasingly investing in IT coordination and in tooling and suppliers' raw material inventory, FSJC can improve efficiency of information and share more risk with suppliers, which will improve the relationship between suppliers and increase the flexibility of suppliers to carry and allocate raw material for FSJC.

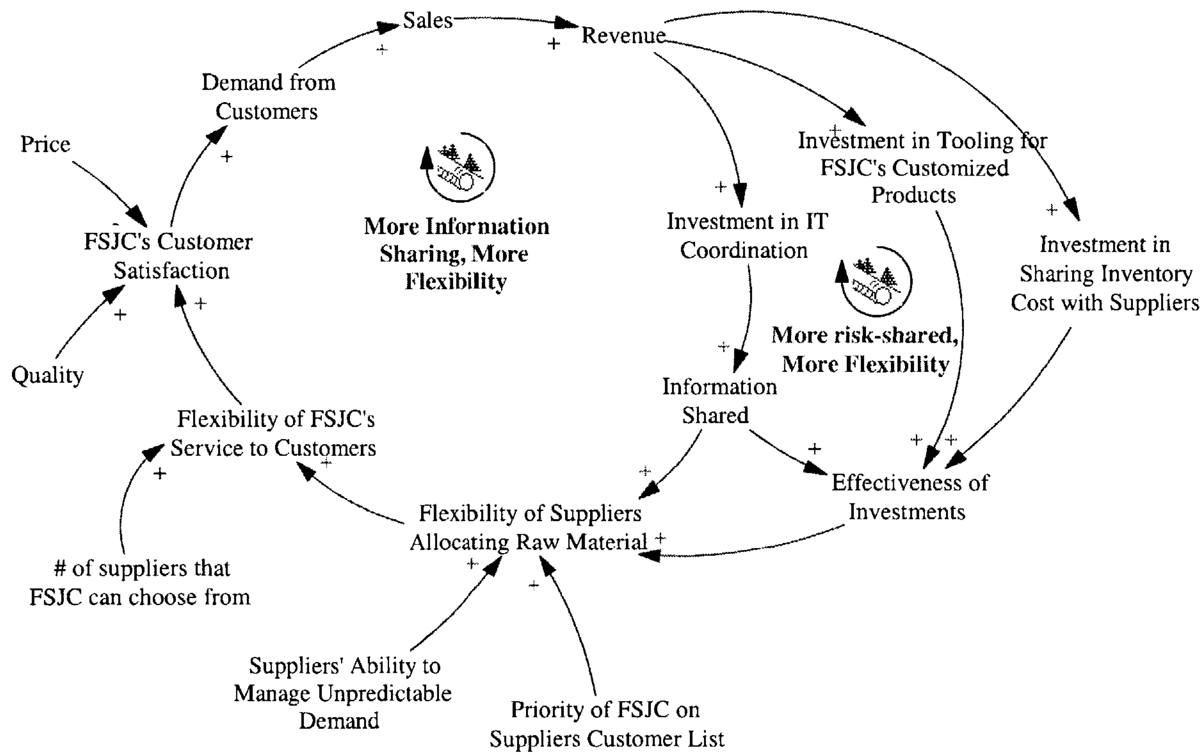

Figure 3-3 Dynamics Hypothesis 3: Flexibility

3.4 Dynamic Hypothesis 4: Increase attractiveness to suppliers

By attracting more demand from customers, FSJC increases the demand for suppliers' capacity, which increases the number of suppliers that FSJC can choose from. The more suppliers FSJC can choose from, the more competitive price FSJC can get and the more flexibility FSJC can provide to the OEM customers. However, the competition in the industry has driven competitors to consolidate their suppliers and decrease the number of suppliers that FSJC can choose from.

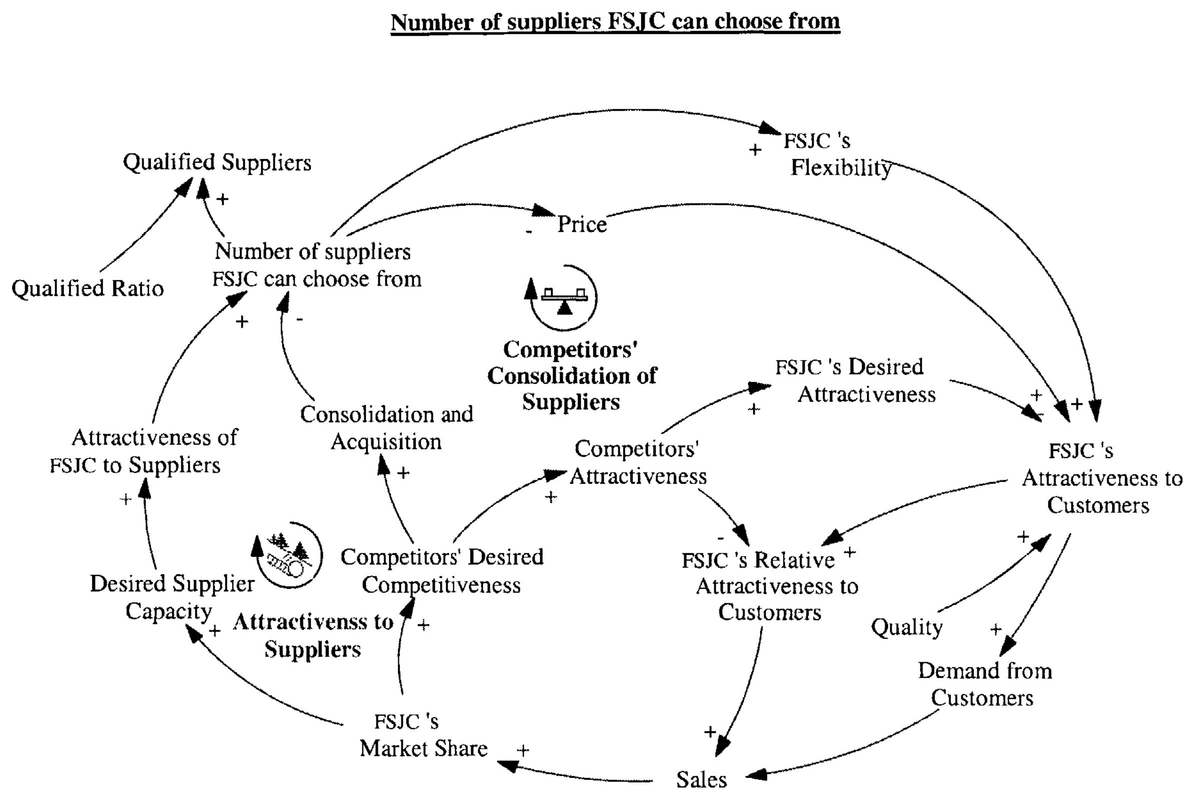

Figure 3-4 Dynamics Hypothesis 4: number of suppliers

3.5 Dynamic Hypothesis 5: Increase suppliers leverage

With more suppliers to choose from, FSJC can choose to work with those suppliers that have higher leverage to purchase raw material. Thus those suppliers are able to better deal with huge demand increase for supplier capacity and guarantee more on-time delivery to FSJC, which will further guarantee FSJC's on-time delivery and increase FSJC's attractiveness and market share. The on-time delivery is one of the key factors that influence FSJC's attractiveness in the EMS industry. FSJC's competitiveness will further attract more demand from OEM customers and more suppliers to work and grow together with FSJC.

Leverage

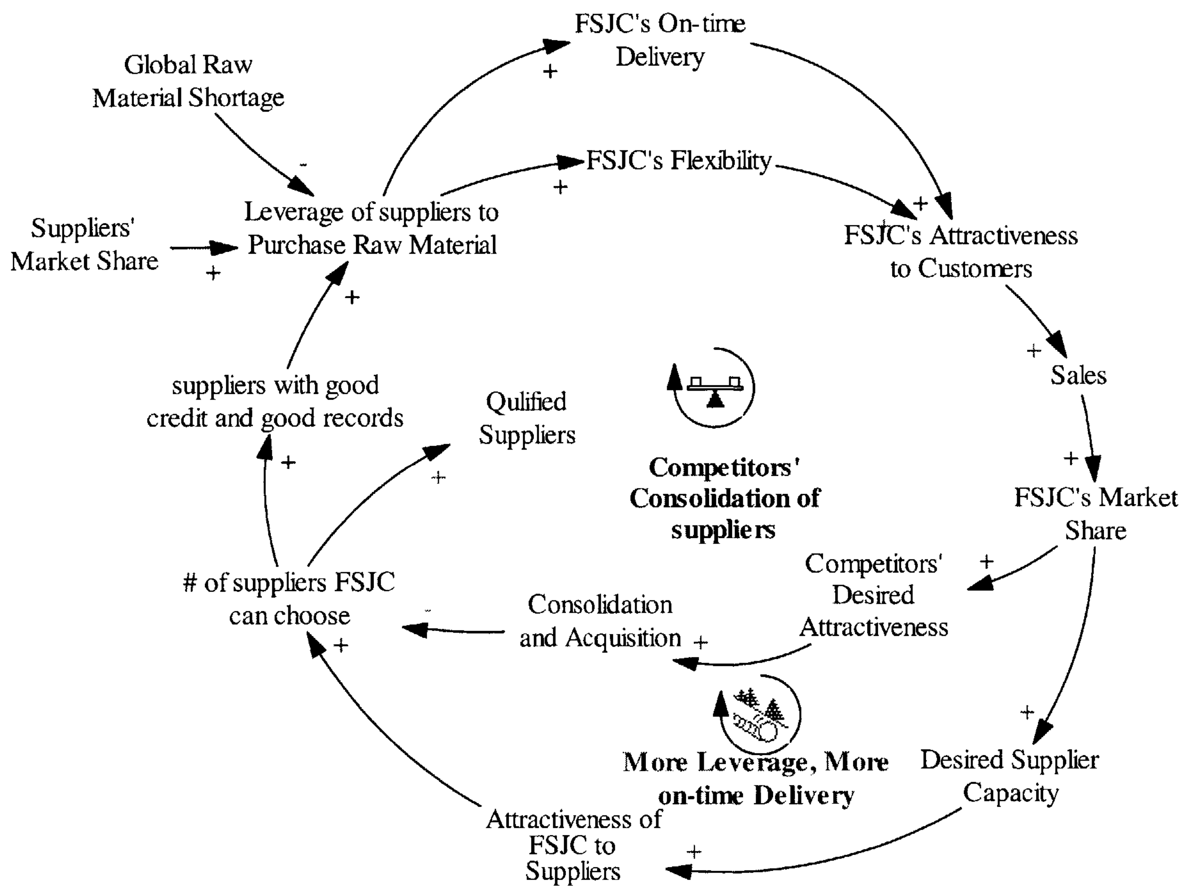

Figure 3-5 Dynamics Hypothesis 5: Leverage

3.6 Insights

The following are some insights coming from discussion of dynamics hypotheses and the process of developing the casual loop diagrams.

1. FSJC should concentrate on partnership with qualified suppliers and build more trust with these suppliers.
2. Through investing in specialized tooling and supplier raw material inventory, FSJC could share more risk with suppliers.
3. FSJC should share more information with suppliers and work with both customers and suppliers to increase the visibility of the supply chain.

4. In addition to sharing more information with supplier, FSJC should help suppliers to improve the efficiency of suppliers' using the forecast.
5. FSJC should involve the supplier earlier in OEM customers' new product design.
6. FSJC should improve not only the flexibility from suppliers but also the flexibility of internal planning and manufacturing.
7. By increasing customer satisfaction of the high-end customers, FSJC can take more responsibility from customers and bring more business to suppliers.
8. FSJC should pay bills to suppliers on time.

Chapter 4 Modeling

In chapter 3, we discuss the dynamics hypotheses and develop casual loop diagrams to capture the endogenous explanations that are responsible for the behavior pattern in the reference modes. In this chapter, we will start modeling by first choosing a hypothesis and then transforming it into models in terms of flows and stocks structure. To do so, we will convert the conceptual diagrams to a fully specified formal model, complete with equations, parameters, and initial conditions. Formalization of models will help us to recognize vague concepts and resolve contradictions during the conceptual phase.

4.1 Choose the first loop to model

A good strategy is to start with what is easiest and most tangible and work towards what is hardest and most abstract. In this project, we choose the priority loop which is central and essential in the causal loop diagram. This is also the part that we understand most clearly.

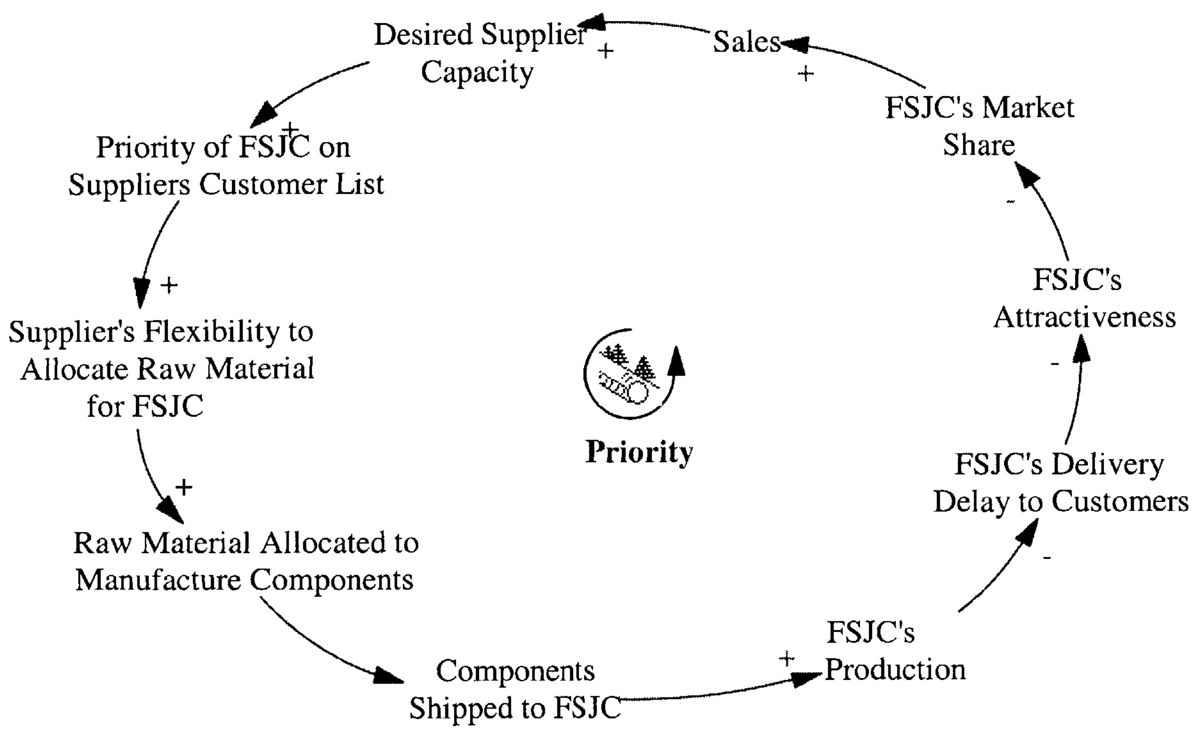

Figure 4-1 Priority Loop

4.2 Mapping subsystems to Molecules

Formalized by Jim Hines in the 1990s, Molecules are small pieces of structure that enables experienced modelers to develop models much faster than beginners. With these building block structures stored in their heads, experienced modelers make it much easier to formulate most equations. Figure 4-2 shows a mapping of the priority loop with several elements in the molecules.

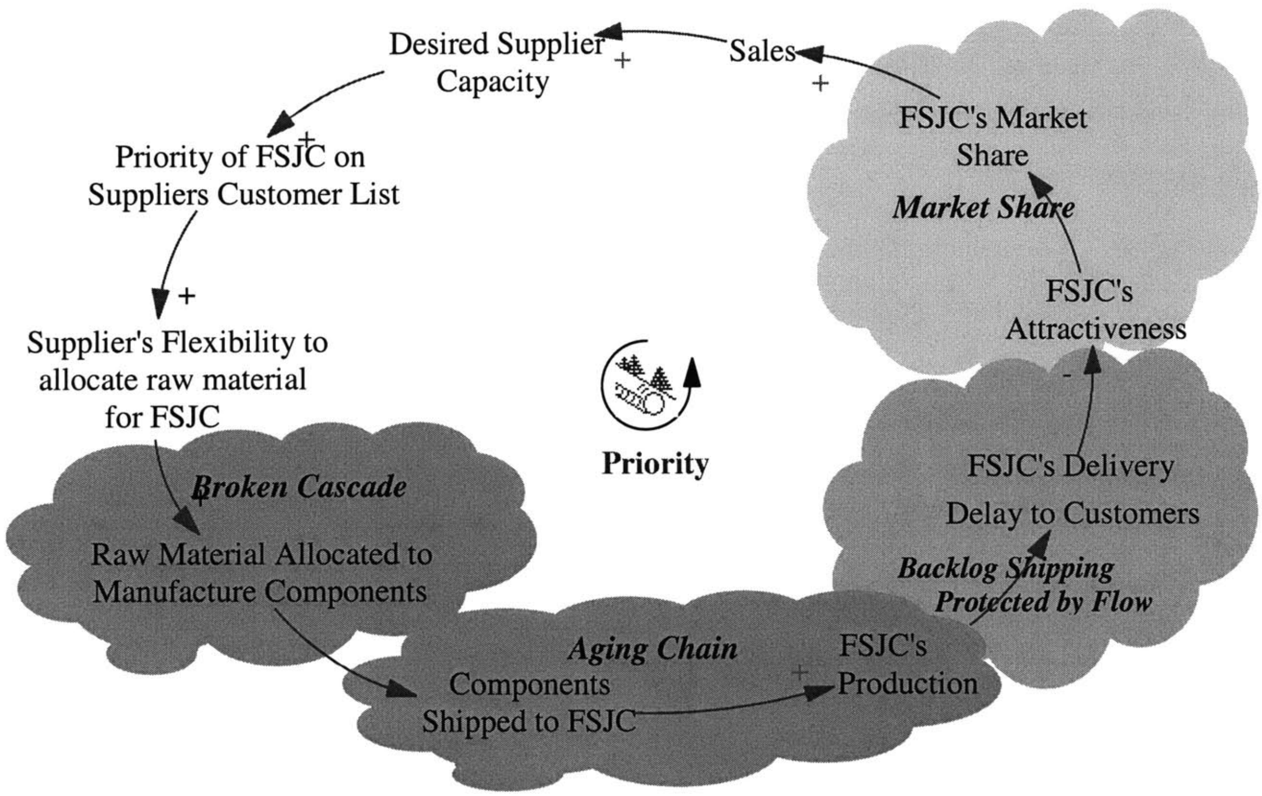

Figure 4-2 Molecules Mapping

4.3 Modeling

4.3.1 FSJC's Manufacturing Sub-Model

In order to reduce the time-to-market and meet customers' specialized demand, FSJC operates with an assemble-to-order model, in which final assembly and testing are based on actual customer demand while components is replenished based on forecast. The following graph shows the manufacturing process at FSJC.

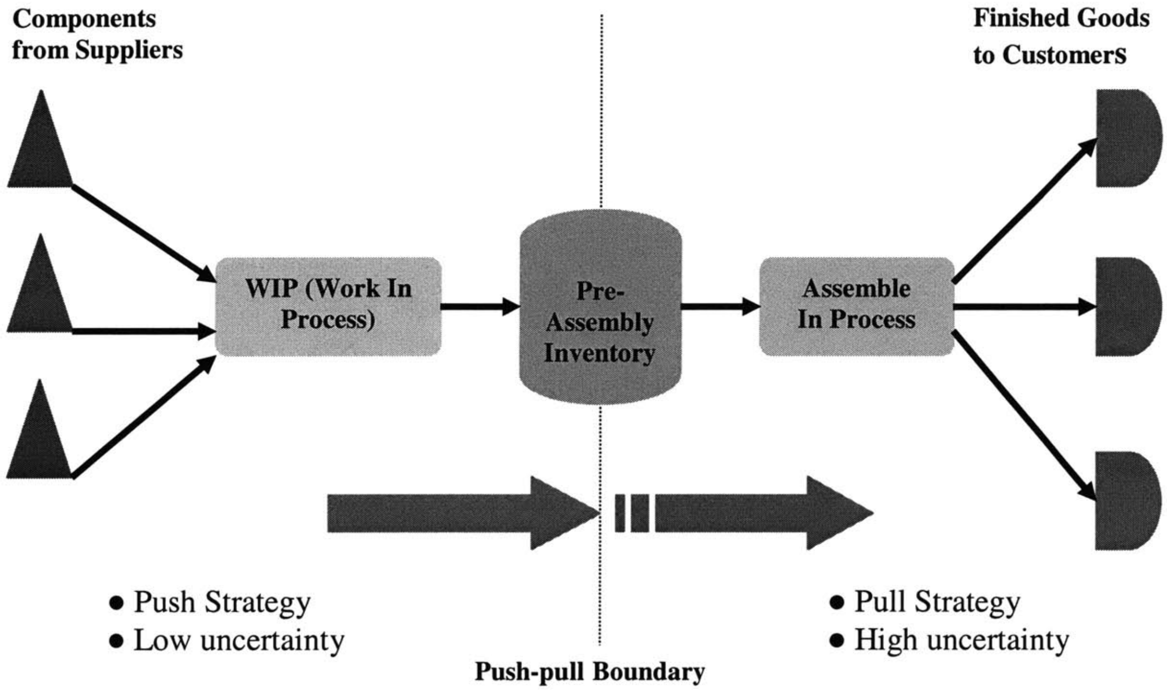

Figure 4-3 Manufacturing Process: Push-Pull System

In this push-pull system, the pre-assemble inventory works as a buffer between FSJC 's manufacturing process and final assembly process. FSJC tries to keep zero raw material (components) inventory and zero finished goods inventory. It orders components from suppliers based on forecast, manufactures and builds up the pre-assemble inventory. When FSJC receives actual customer orders, it pulls sub-assemblies from pre-assemble inventory and assembles them according to customer's particular requirements. However, when the pre-assemble inventory drops below the desired level, FSJC releases purchasing orders to suppliers to replenish additional components, which give the suppliers' manufacturing process a pull signal.

Due to the different mechanisms in push system and pull system, our production model for FSJC also consists of two parts. Based on Aging Chain Molecule[2] and Structure of Production

[2] See Jim Hines, Molecules of Structure, Version 2.0, (2004), P25-26

Starts Model[3], we develop the production sub-model for the traditional push system (Figure 4-4). Based on Level Protected by Flow Molecule and Backlog Shipping Protected by Flow Molecule[4], we develop the final assembly and shipping sub-model for the pull system (Figure 4-5).

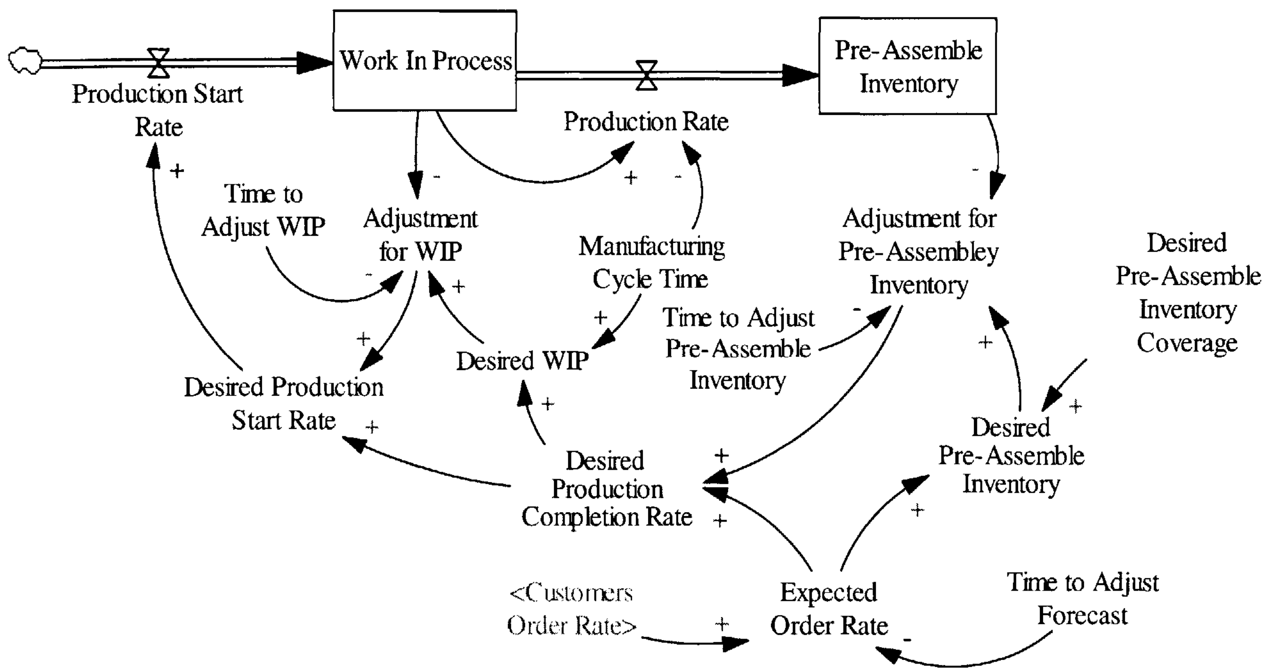

Figure 4-4 Manufacturing Sub-Model (Part 1, Production)

[3] See John D. Sterman, Business Dynamics, 2001, P709-715,
[4] See Jim Hines, Molecules of Structure, Version 2.0 (2004), P126-129

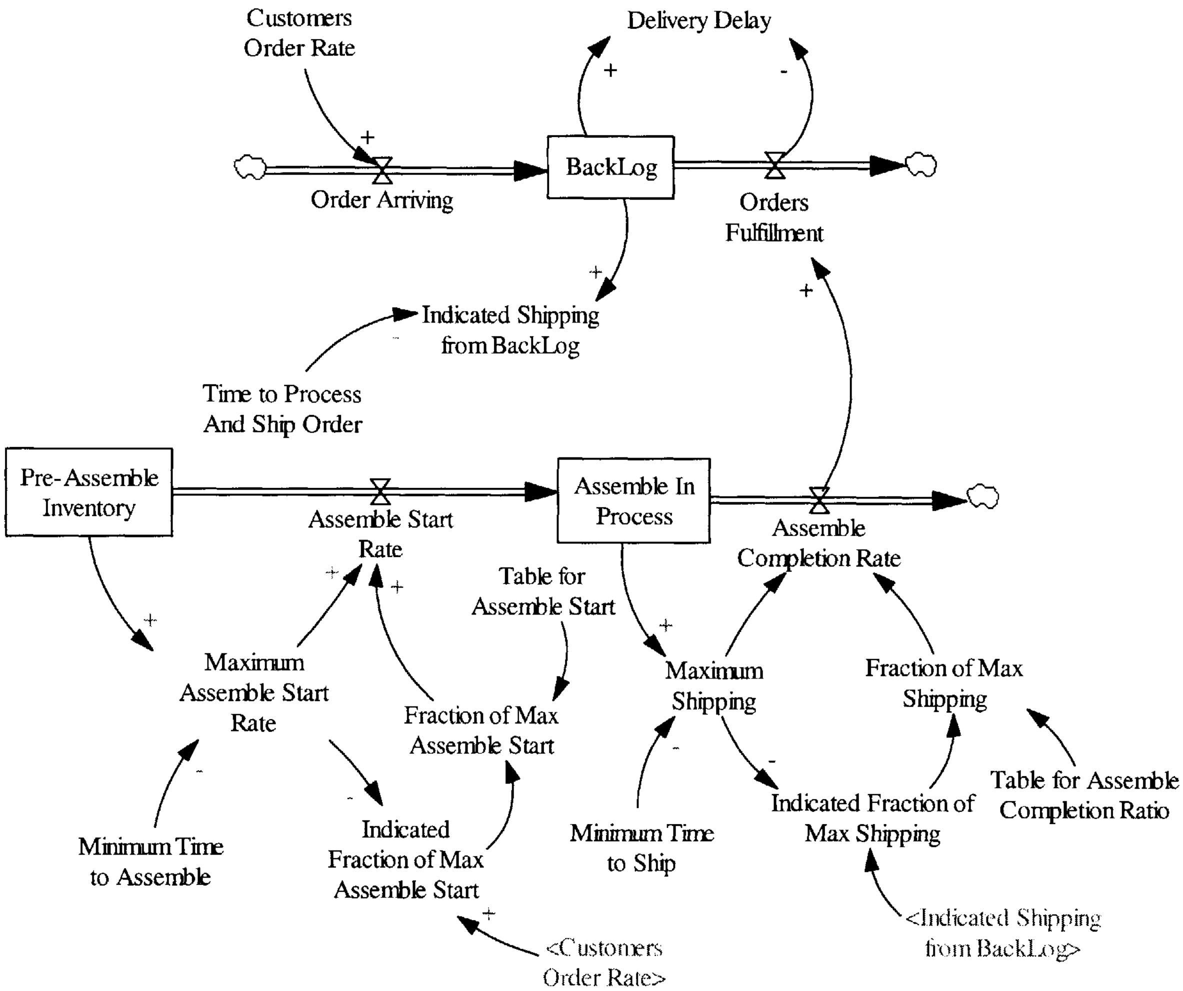

Figure 4-5 Manufacturing Sub-Model (Part 2, Assembly and Shipping)

4.3.2 Market Share Sub-Model

In the EMS industry, EMS providers compete on price, quality, time-to-market, and flexibility. However, in this project, we are most interested in the impact of on-time delivery on the attractiveness of FSJC. To build on Market Share Molecule[5], we develop market share sub-model for FSJC (Figure 4-6).

[5] See Jim Hines, Molecules of Structure, Version 2.0, (2004), P88- P90

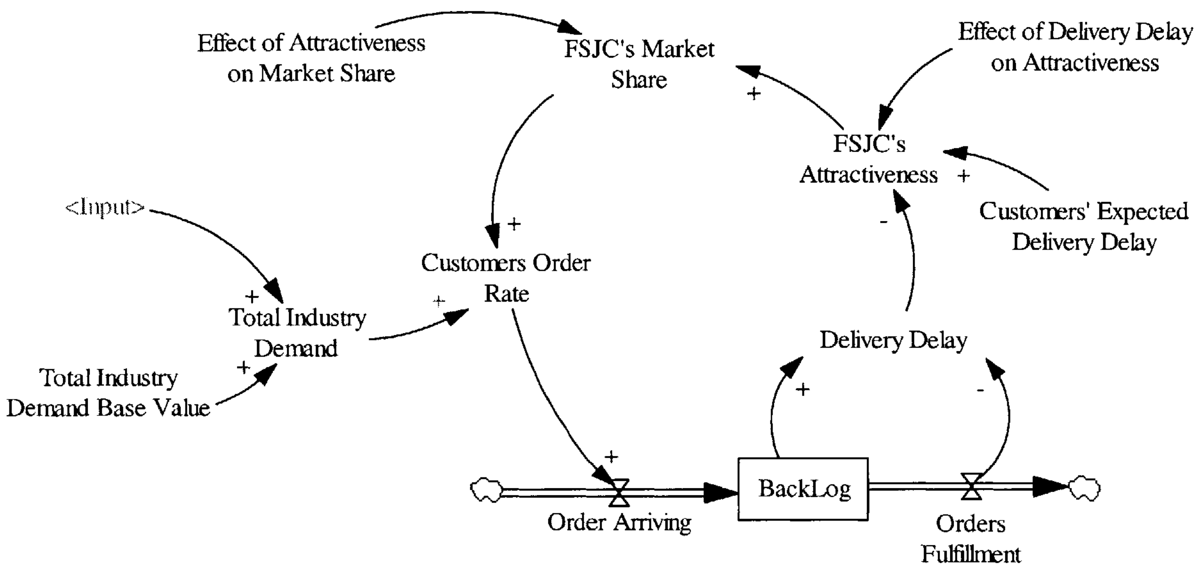

Figure 4-6 Market Share Sub-Model

4.3.3 Supplier's Production Sub-Model

In this project, we concentrate on those suppliers that manufacture customized components for FSJC. The suppliers purchase raw material based on the forecast that FSJC shares and build up pre-assembly inventory, which is also the push-pull boundary for suppliers manufacturing system. Supplier's Production Model is formulated in a similar way as that of FSJC. The following figure 4-7 shows the sub-model of the supplier's production.

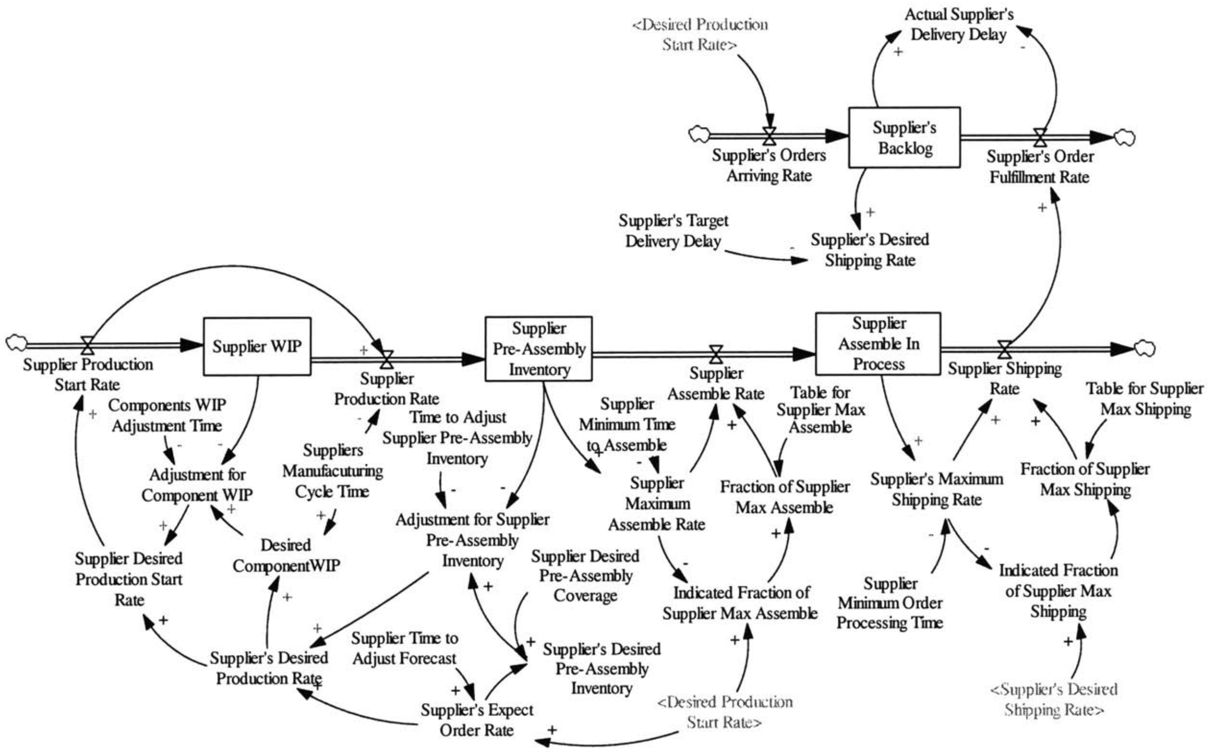

Figure 4-7 Supplier's Production Sub-Model

4.3.4 Raw Material Allocation Sub-Model

Suppliers try to keep minimum raw material inventory. When there is a signal from production line for additional raw material, suppliers allocate raw material based on customers' priority and flexibility. The demand customer can bring to the suppliers, the higher the priority the customer, and the more flexibility that suppliers can allocate raw material to the production line for the customized components. Based on Broken Cascade Molecule[6], we develop the raw material allocation model as follows (Figure 4-8).

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[6] See Jim Hines, Molecules of Structure, Version 2.0, (2004), P14-P16

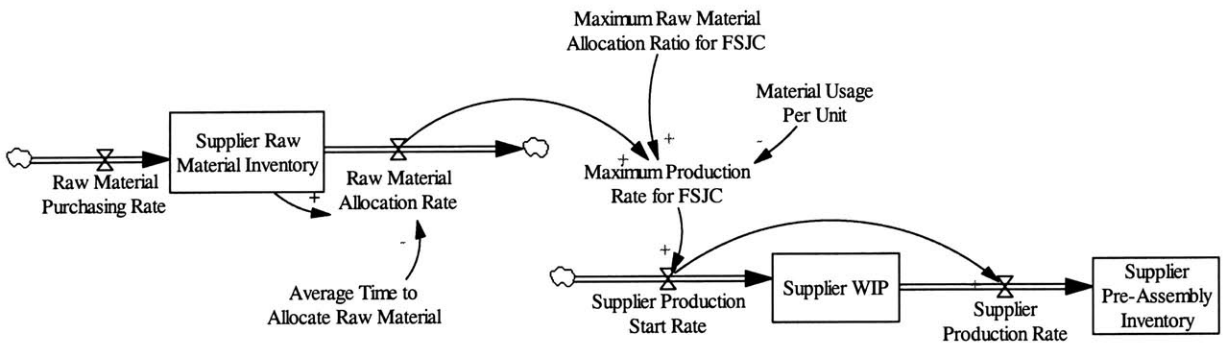

Figure 4-8 Raw Material Allocation Model

4.3.5 FSJC- Supplier Partnership Model

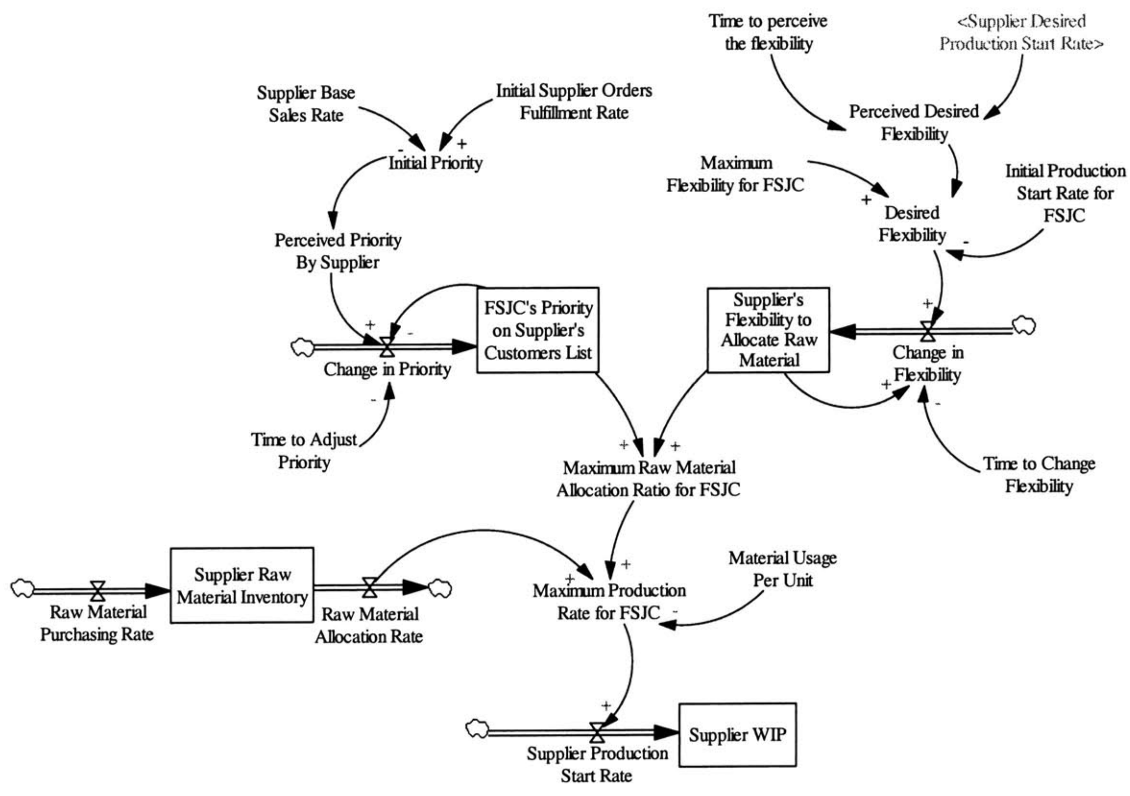

Figure 4-9 FSJC- Supplier Partnership Model

The key variables in the partnership model are FSJC's priority on suppliers' customers list and suppliers' flexibility to allocate raw material for FSJC. The priority is determined by the demand that FSJC brings to the suppliers. In addition, the flexibility that suppliers can provide depends on the FSJC's priority, that is, the demand volumes that FSJC can bring to FSJC. Basically, suppliers provide more flexibility to bigger customers than to smaller customers. In the model, we assume that is a linear relationship between priority and flexibility. FSJC is concerned about whether it can get enough raw material allocation when the demand for components increases. In the model, the maximum raw material allocation depends on both priority and flexibility that FSJC gets from suppliers (see figure 4-10). If FSJC cannot get the desired raw material allocation, there will be pressure for FSJC to increase the flexibility. However, the increase flexibility takes time to happen. With adequate raw material allocation, the suppliers can meet their delivery commitment and FSJC can also delivery the finish goods to customers on time. This win-win situation will bring more demand to both FSJC and suppliers.

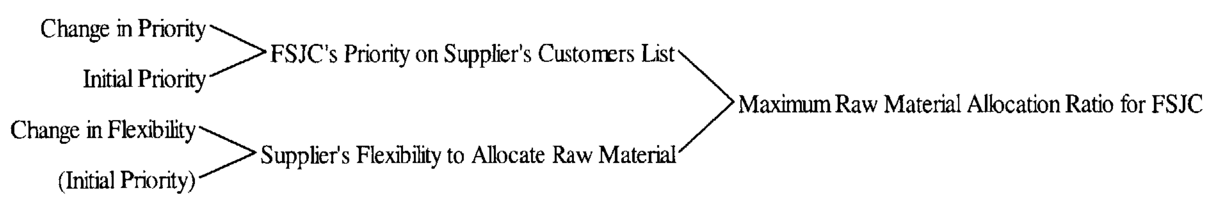

Figure 4-10 Causes Tree for Maximum Raw Material Allocation Ratio for FSJC

Now, we have transformed the priority loop into a model, which consists of five sub-models: FSJC's Production, Market Share, Supplier's Production, Raw Material Allocation, and FSJC-Supplier Partnership. The detailed model documentation is described in Appendix B.

Chapter 5 Model Analysis

In chapter 4 we discuss the whole process from choosing the first loop to model, to mapping a loop to the Molecules, and finally to building a model in terms of flows and stocks. In this chapter, we will analyze the dynamic behavior of the model through different scenarios of simulation.

Before staring simulation, it is essential that the model is in equilibrium, a state that all the stocks and flows remain constant. From equilibrium, we introduce exogenous changes in the input function, which simulates the situations that industry demand increases. FSJC is concerned about whether it can get enough raw material allocation from suppliers when the total industry demand picks up. We explore the behavior patterns of the model by introducing two demand scenarios: (1) increase the total industry demand by 20% using step function, and (2) increase the total industry demand by 10% three times using three step functions.

5.1 One Step Increase Demand

After setting the model in equilibrium, we increase the total industry demand from 10,000 units/week to 12,000 units/week at week 5. The initial value of FSJC's market share is 10%. Correspondingly, the demand for FSJC's products increases from 1,000 units/week to 1,200 units/week. Figure 5-1 and 5-2 represents the production rate and inventory level at FSJC respectively.

This demand increase gives FSJC's final assembly line a signal to increase the assembly rate, which lowers the pre-assembly inventory. When the pre-assembly inventory drops below the desired level, which will result in the adjustment of production rate and production start rate. The desired production start rate is a demand signal for suppliers, which triggers the suppliers' final assembly line for components. The increasing assembly rate for components will lower the suppliers' pre-assembly inventory level and send a signal to supplier's production line to manufacture additional sub-assemblies for components. If there is inadequate raw material, the suppliers need to purchase more raw materials and provide more available raw material allocation.

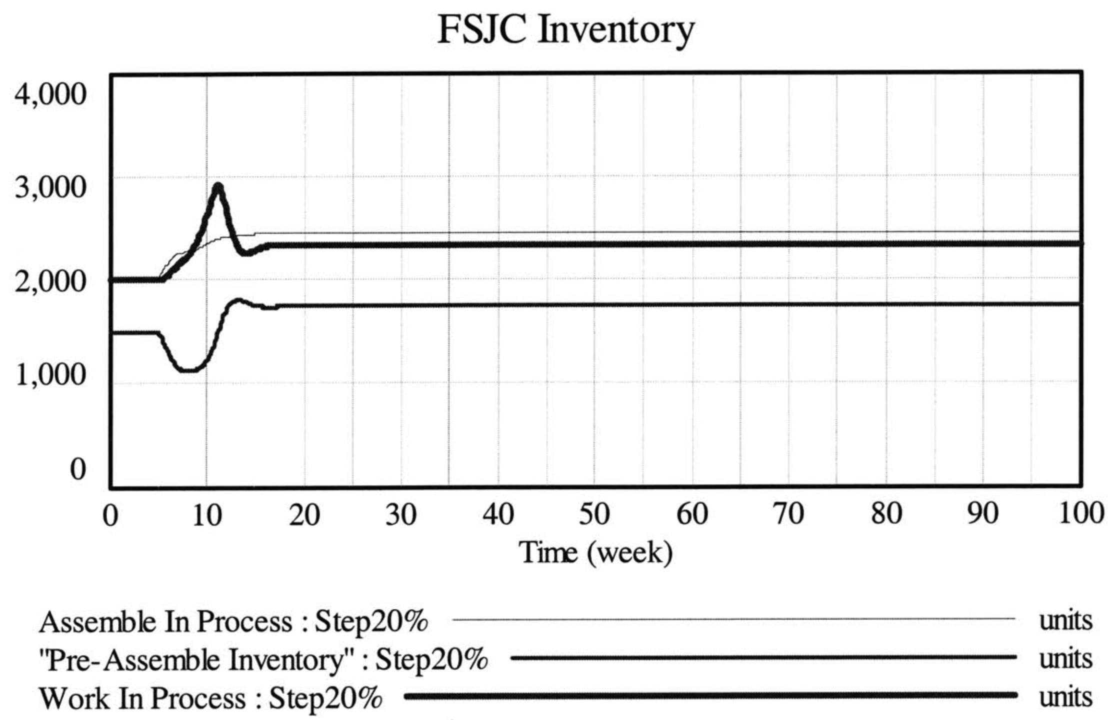

Figure 5-1

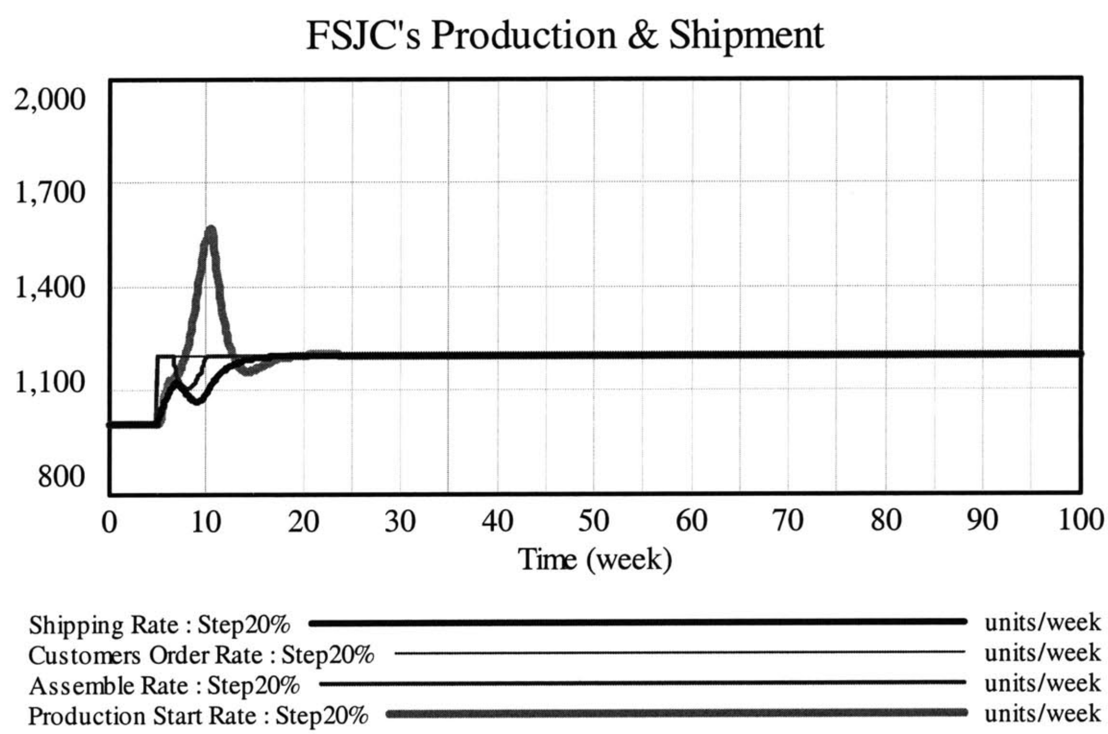

Figure 5-2

However, we find out that huge oscillations happen at the supplier's manufacturing process.

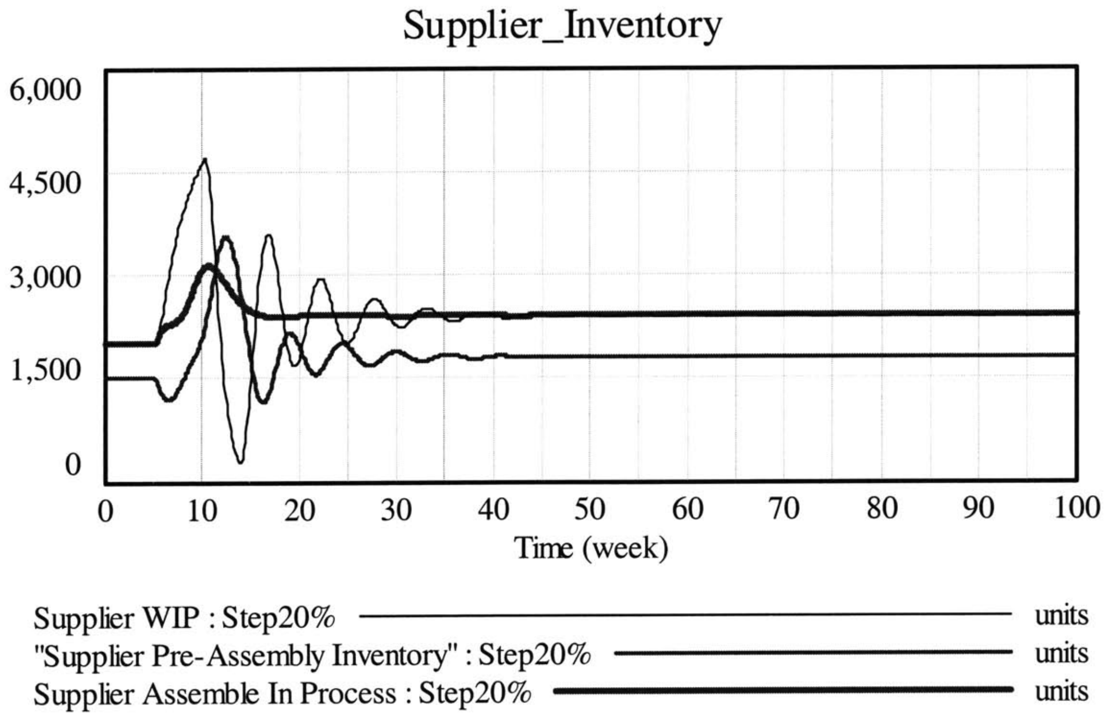

Figure 5-3 Suppliers Inventory

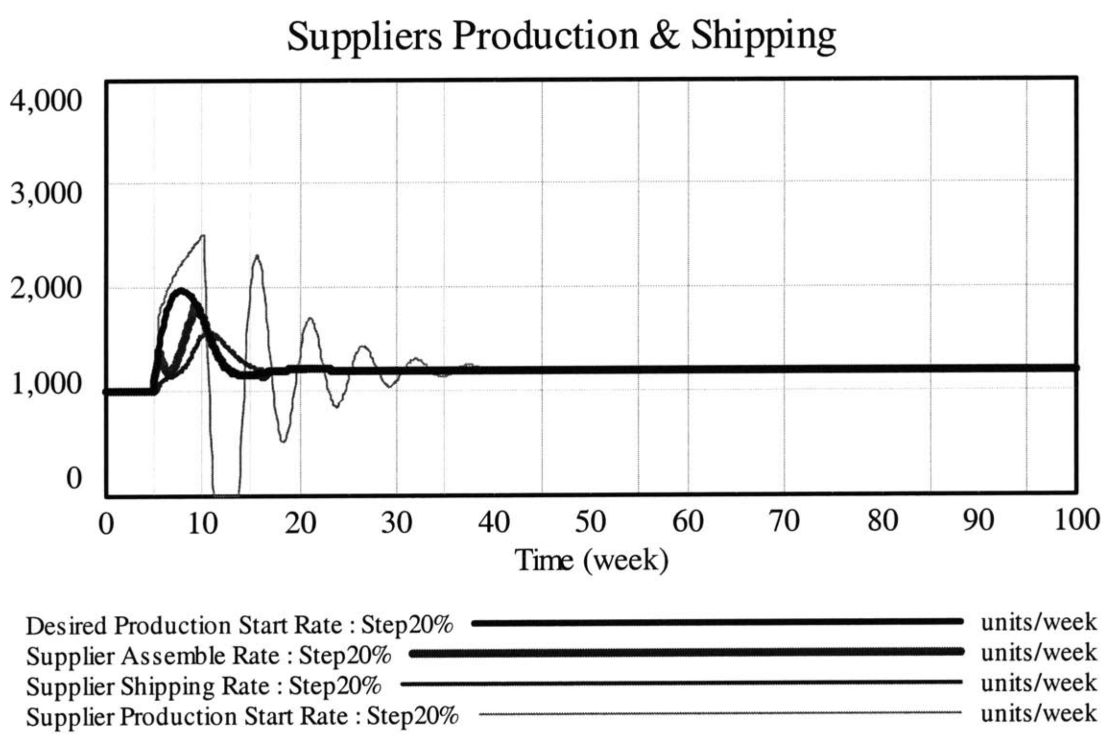

Figure 5-4 Supplier Production & Shipping

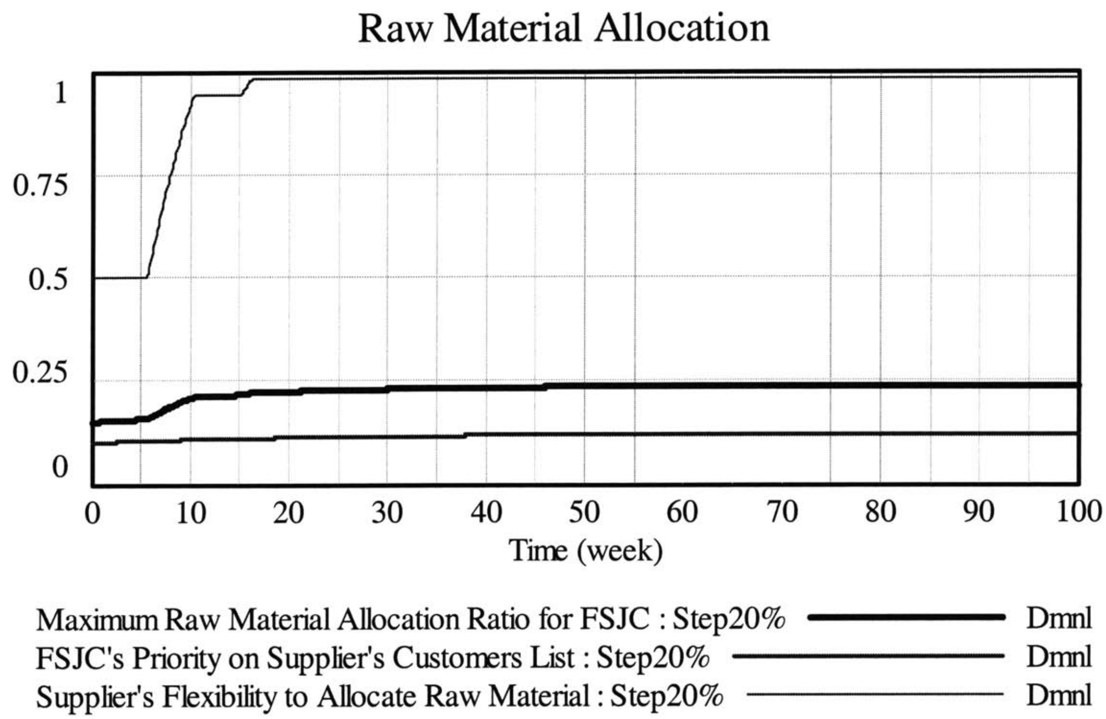

Figure 5-5 Raw Material Allocation

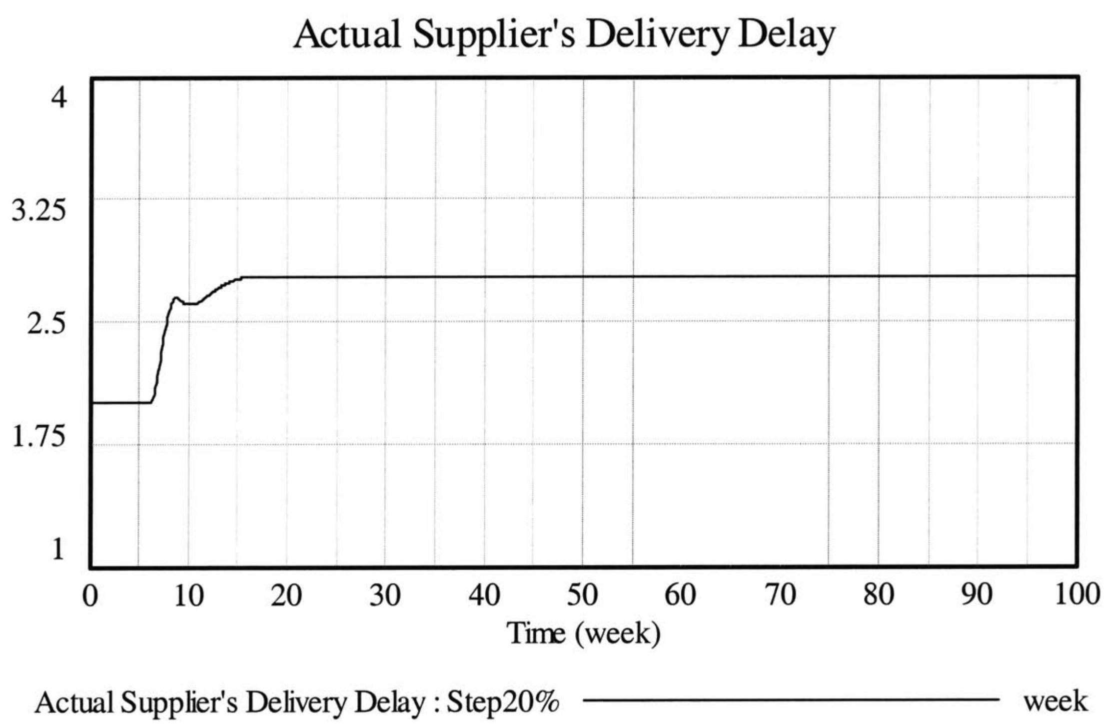

Figure 5-6 Supplier's Delivery Delay

As total industry demand step up by 15%, we observe that both the priority of FSJC on suppliers' customer list and suppliers' flexibility to allocate raw material increases gradually, which at the same time increase the maximum raw material allocation to FSJC. However, even when we increase the raw material allocation to a desired level, which does not pose any constraint on supplier's production start, we observe that the average suppliers delivery delay increases. It is meaningful to find out the root causes for the fluctuation at supplier's manufacturing process and the increased delivery delay. Several important insights come out from the sensitivity analysis, which enables us to explore the potential endogenous explanations for the dynamic behavior of the model. For each parameter, we first double and then cut in half the value while keeping the remaining parameters unchanged.

Initially, FSJC team believes that fluctuation is caused by fluctuation of customer demand. However, the sensitivity analysis results suggest that the structure of the supply chain itself may be responsible for some or all of the observed instability. By increasing supplier time to adjust WIP or increasing supplier time to adjust pre-assemble inventory, we could reduce or even eliminate these fluctuations. In this way, the suppliers updated their work in process more frequently and smooth the adjustment of inventory over longer time, these could help suppliers to level their production process.

Another anti-intuition result from the sensitivity analysis is that when there is inadequate pre-assembly inventory coverage, increased raw material allocation cannot eliminate the fluctuations in suppliers' manufacturing process. At the beginning of this project, FSJC teams think that as long as FSJC can get adequate raw material from supplier, both suppliers and FSJC can meet the on-time delivery commitment. It is true that less flexibility and inadequate raw material allocation increases the suppliers' delivery time. Another very important variable to determine the on-time delivery is the suppliers' desired pre-assembly inventory coverage. Furthermore, due to the inevitable amplification of production from downstream to upstream of the supply chain, in order to buffer the same variability of customer demand, the suppliers need to have higher pre-assembly inventory coverage than FSJC does.

Finally, it is very important that FSJC coordinates with both suppliers and customers to reduce the average testing and order process time, which will reduce the total time-to-market and increase FSJC's attractiveness and market share. Figure 5-7 shows that a 25% reduction of order process time will result in increased market share.

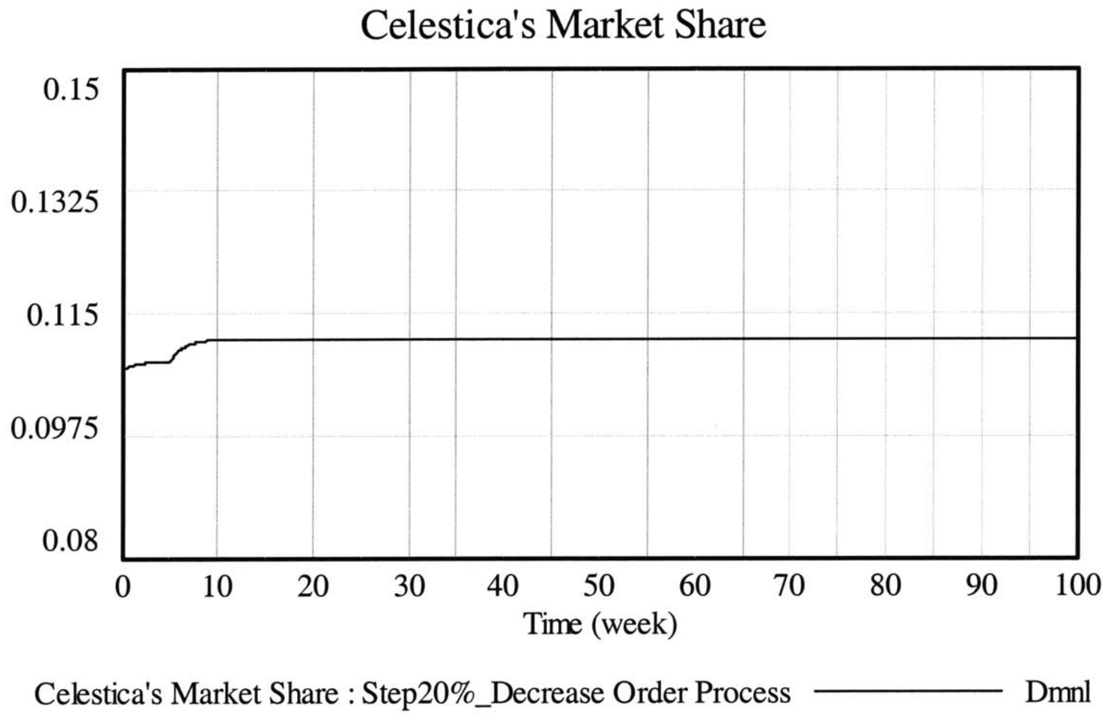

Figure 5-7 Market Share

5.2 Three steps increase demand

FSJC teams are concerned about gradually increased customer demand. In this case, we use the input function to increase the customer demand 15% at week 5, another 15% at week 8, and additional 15% at week 11. From figure 5-8 to 5-11, we can see that the model behaves the similar pattern as before except that the dramatic increased amplification ratio of production both at FSJC and suppliers due to the large variance of the total industry demand.

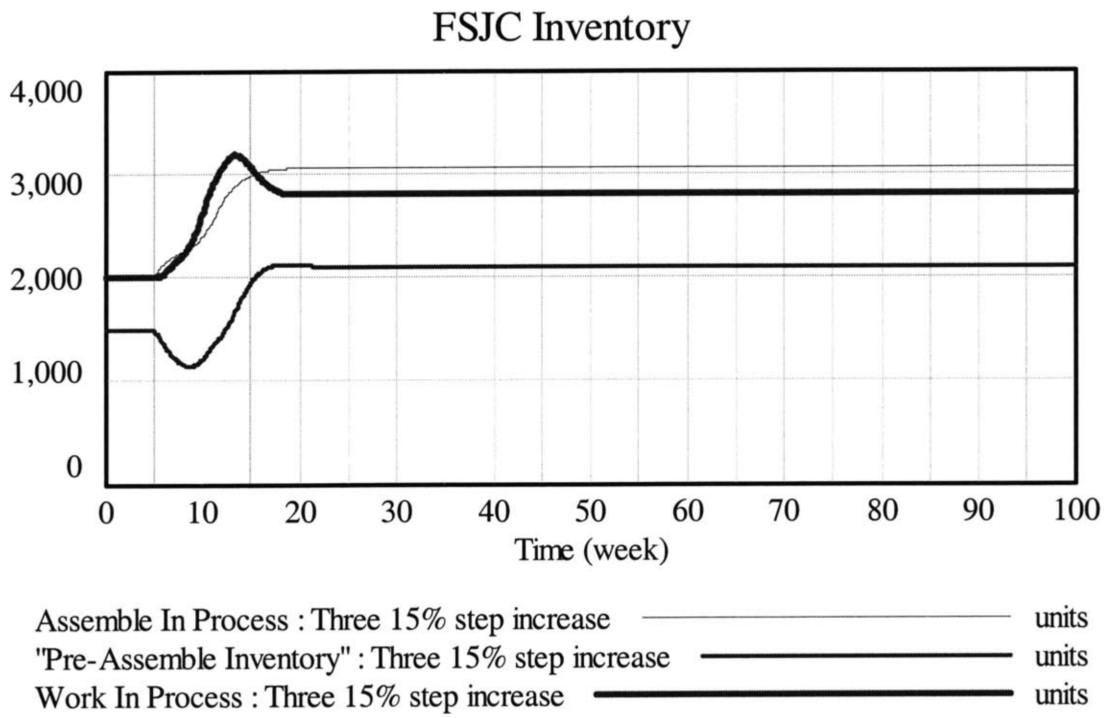

Figure 5-8

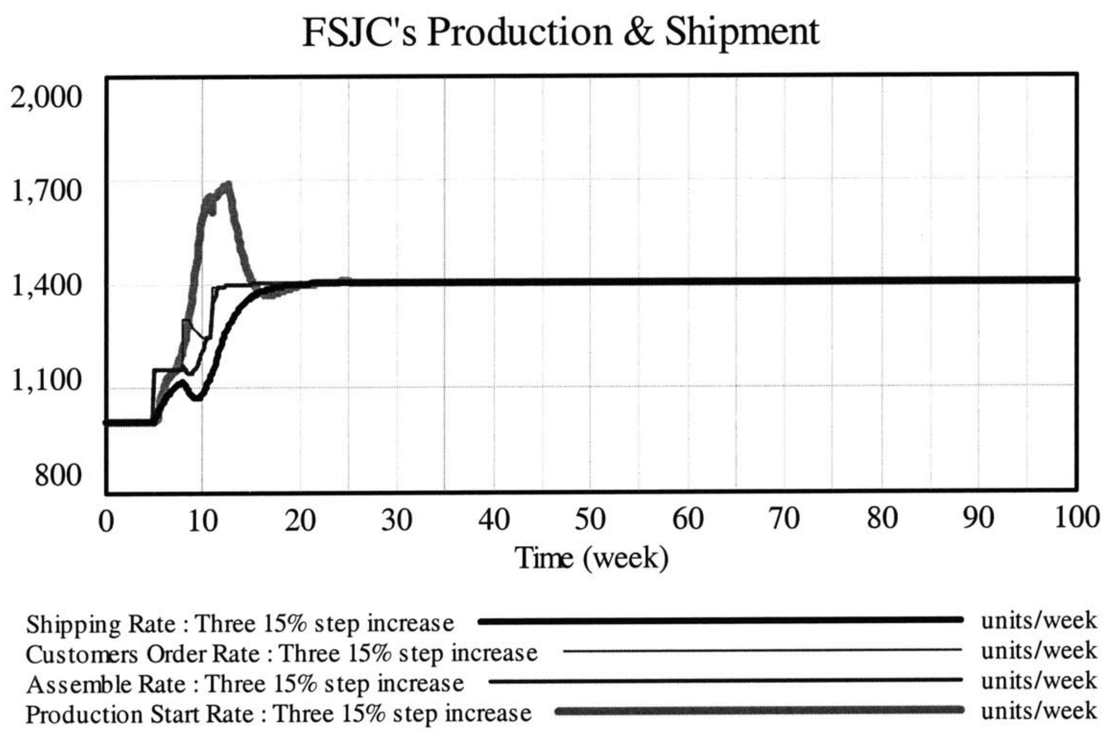

Figure 5-9

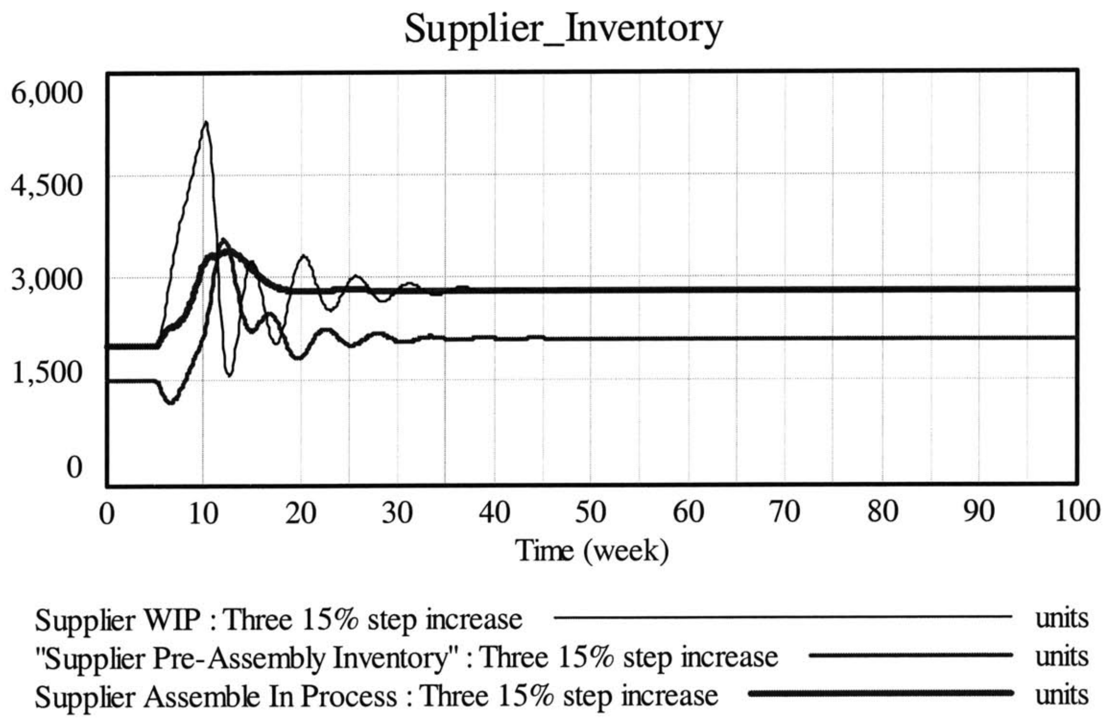

Figure 5-10

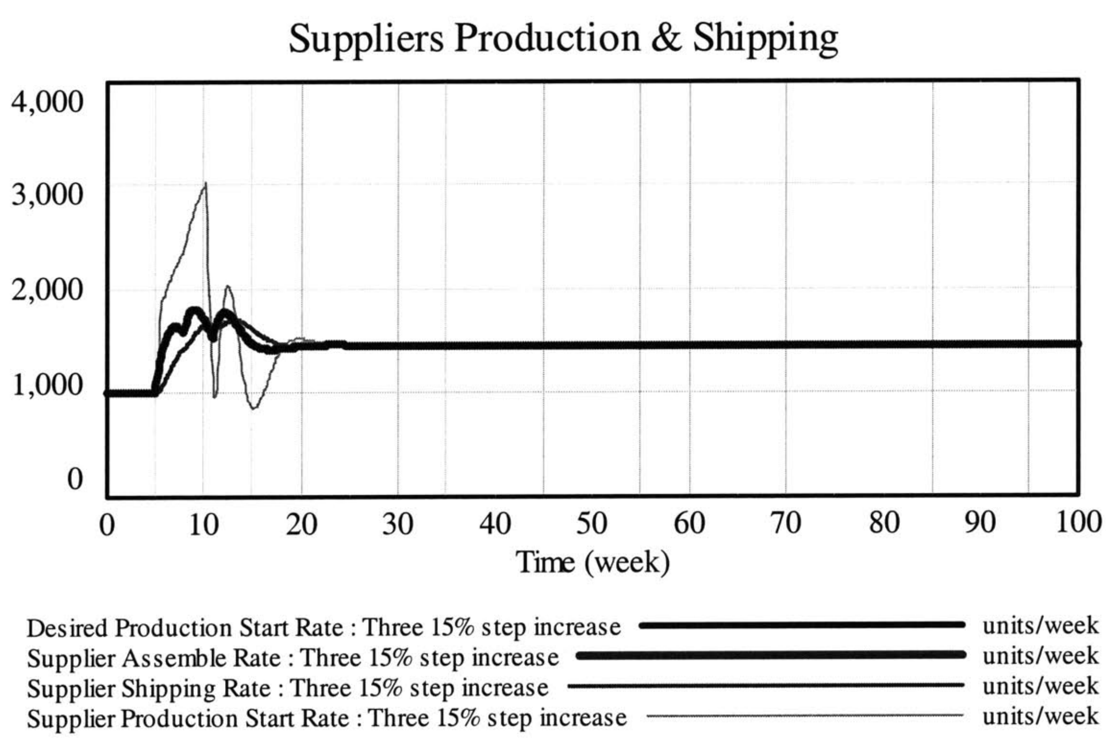

Figure 5-11

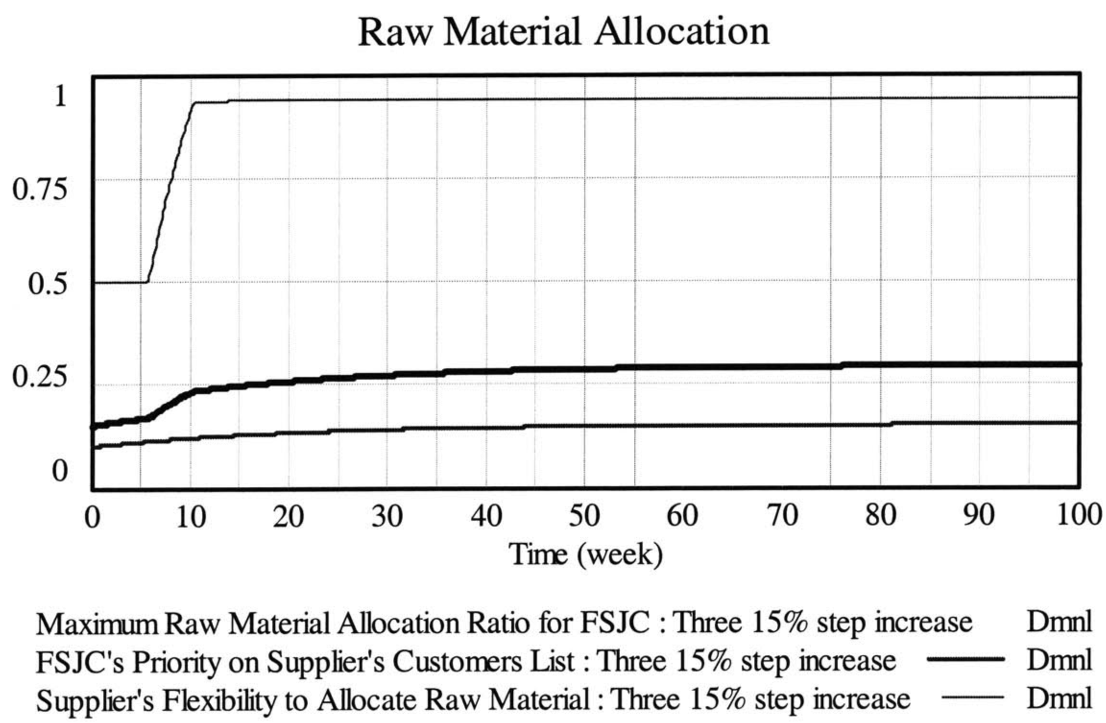

Figure 5-12

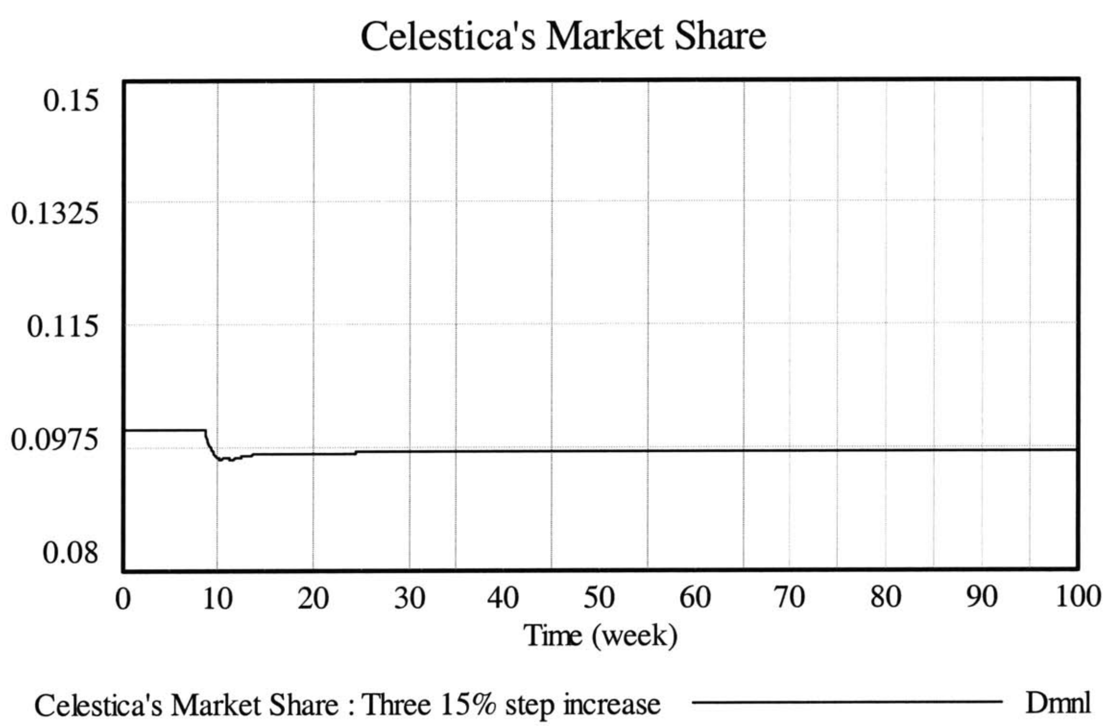

Figure 5-13

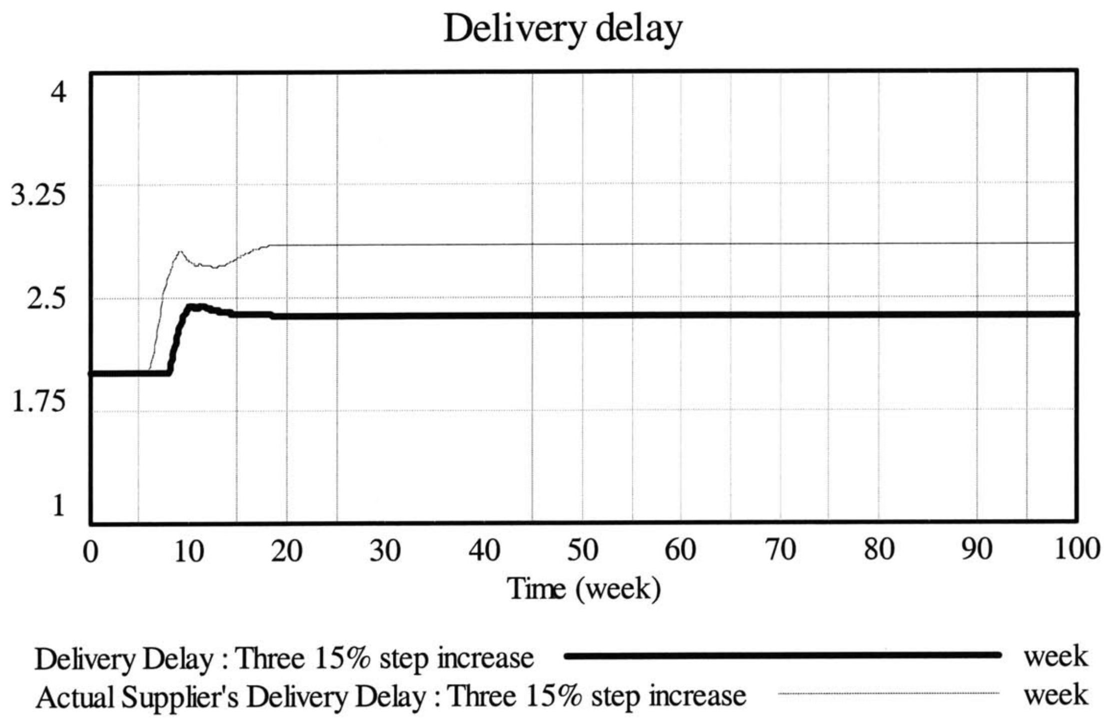

Figure 5-14

Although the increased priority and flexibility provide enough raw material allocation to FSJC, we observe decreased FSJC's market share as a result of increased both supplier delivery delay and FSJC's delivery delay. This scenario gives us a signal that in order to fix the problem of late delivery delay and decreased market share, we need to look at some parameters in the model, especially the coordination of the values between FSJC and suppliers. When we increase the demand by 20%, in order to reduce the fluctuation and delivery delay, we can simply double or cut in half one parameter. However, in the case with three step increase by 15%, it is difficult for us to achieve the same goal by just changing one or two parameter. The larger variability of demand increase calls for the collaboration of adjusting parameters at both FSJC and supplier side. The priority and flexibility may pose a constraint for the suppliers' production, however, extreme high raw material allocation cannot solve the problems of production oscillation and delivery delay. To deal with dramatic increased demand, both FSJC and suppliers need to collaborate to adjust pre-assemble inventory coverage and time to assemble and process orders to avoid delivery delays, to decrease the time to adjust WIP to be more responsive to market changes, and to increase time to adjust pre-assembly inventory to smooth the production process.

Chapter 6 Insights and Recommendations

In chapter 5, we analyze the dynamic behavior of the model in two different scenarios of increased total industry demand. We present the results of the simulation and discuss the insights arising from the simulation. In this chapter, we will reflect the learning journey throughout conducting this project, summarize the insights from the whole modeling process, and recommend strategies for FSJC to deal with increased demand. Finally, potential areas for further research are discussed.

6.1 Project Reflection

By partnering with FSJC to conduct this project, we gain a deeper understanding of the capacity issues in terms of raw material availability and the supplier partnership in the EMS industry. During the whole journey of following the standard approach, from starting the project with list of variables, reference modes, and problem statement, to dynamic hypotheses, modeling, and analysis, I feel that the most challenges come from effectively and correctly converting the causal loops into models. The modeling process provides us an opportunity to correct and detail the cause effect relationship in the hypothesis, to transform the cause loops into flows and stocks structure that is responsible for the behavior in the reference modes. Since the modeling process is an iterative process, converting the loops into models requires us to reflect all the work we have done and to adjust reference modes, hypothesis as needed. Mapping the loops with Molecules is extremely helpful and effective.

Another challenge is to find the effective way to "sell" system dynamics to senior managers in a short time. The systems dynamics approach helps the managers to clearly understand what the real problems are and to find the root causes that are responsible for the burning problems. Insights throughout the whole project demonstrate the power of system dynamics to help senior managers to understand the complex business issues and make better decisions.

6.2 Insights

Insights are the most valuable deliverables for system dynamics projects. We summarize all the insights coming from this project as follows:

1. Strong partnership with suppliers is extremely important for EMS providers with virtual integration model when market picks up.
2. Increased raw material allocation can be achieved by either bring more business to suppliers to increase the priority or build strong relationship to increase the flexibility, or both.
3. In order to increase the priority, FSJC should try to reduce the supplier base, which would consolidate demands for supplier capacity and increase the demand for qualified suppliers.
4. Raw material allocation is essential but not a panacea for all the problems caused by demand changes. To deal with dramatic demand changes, the flexibility of both suppliers' and FSJC's manufacturing processes are also very important.
5. Oscillations of production rate and oscillations of supplier capacity gap may be endogenous and caused by internal actions such as time to adjust work in process and time to adjust pre-assembly inventory.
6. Pre-assembly inventory is a buffer to separate the fluctuation of production and final assemble according to customer orders. Inadequate pre-assembly inventory will cause late delivery and lose future orders from customers.
7. Work in process should be adjusted more frequently than the pre-assembly inventory. The shorter the time to adjust WIP, the more responsive to market is. The longer the time to adjust inventory, the smoother and more stable the production processes are.
8. The amplification effect from downstream customers to the upstream supplier throughout the supply chain. FSJC needs to take into consideration of the effect of increased demand for components on suppliers' manufacturing.
9. In addition to realize the amplification effect, FSJC and suppliers should design different strategies to adjust WIP and pre-assembly inventory accordingly.
10. Take into account the unavoidable delays to build strong partnership with suppliers.
11. Different inventory policies and replenishment strategies are needed to deal with different demand variability.

6.3 Recommended Strategies

Based on the insights that we gained throughout the project, we recommend the following strategies to FSJC's senior management team. The following table shows both the momentum polices known before conducting this project and recommended strategies after the modeling process.

Momentum Policies	Recommended Strategies
Early involvement of suppliers, FSJC, and OEM customers in the new product development.	Collaborate with both suppliers and customers not only to prepare for raw material usage for new product introduction, but also to improve the visibility of supply chain to better deal with demand variability.
More certainty about demand in terms of commitment to customers' demand and reserved capacity to suppliers.	
Increase FSJC 's priority on suppliers' customer list	Consolidate the demand for supplier capacity and increase the priority on suppliers' customer list.
Reduce the supplier base and build strong partnership with qualified suppliers.	Build strong partnership with a small number of suppliers and increase the flexibility that suppliers can offer to FSJC, including the flexibility to carry and allocating raw material for FSCJ, and the flexibility of manufacturing.
Share more risk with suppliers by investing in tooling and raw material inventory	Identify the potential areas that FSJC can share risk with suppliers, such as specialized tooling and raw material inventory. Take actions now and consider the unavoidable delays to build strong partnership with suppliers
Provide better service to the current customer base and attract more tier-1 customers.	Recognize the amplification effect from downstream to upstream of supply chain and implement Collaborative Planning, Forecasting and Replenishment with suppliers and customers.

Grow with small entry-level startup companies.	Realize the importance of pre-assembly inventory, especially in the case of huge demand increases and set an appropriate level of pre-assembly inventory to prepare for demand variability.

Table 6-1 Comparison of Momentum Policies and Recommended Strategies

From the above table, it is obvious that the recommended strategies coming after the modeling are concentrated on both the importance of priority and flexibility that suppliers can offer to FSJC and the importance of collaboration throughout the supply chain.

6.4 Potential Further Research

System dynamics is a powerful tool that can be applied to model a supply chain network to great detail and generate insights for better decision making. The scope of this thesis was scaled down to apply the standard system dynamics method to deep understand the burning issues regarding to supplier capacity in the EMS industry. Time permitting; the scope of the study could have been expanded to include a greater detail of the model. Some of the potential areas for further research are discussed below:

1. Expand the partnership model to include how investments in sharing risk and information increase the flexibility offering from suppliers.
2. Expand the market share model to capture the impact on FSJC's attractiveness besides on-time delivery. The suggested factors are quality, price, and flexibility.
3. Build an additional financial model to reflect the relationship among revenue, budgeting, and cost of building partnership.

Appendix A: List of Variables

Partnership between FSJC and suppliers

1. Priority of FSJC on suppliers' customers list
2. Gap between the desired suppliers capacity and actual capacity
3. FSJC's desired capacity from suppliers
4. Actual capacity that FSJC gets from suppliers
5. Efficiency of suppliers using FSJC' forecast:

FSJC's attractiveness

6. Overall competitive advantages of FSJC
7. Overall competitive advantages of FSJC's competitors
8. cost competitiveness of FSJC's products
9. time-to-market of FSJC's products
10. quality of FSJC's products
11. FSJC's market share in the EMS industry
12. Customer Satisfaction of FSJC
13. Number of tier-1 customers for Celeatica

Suppliers Availability

14. Total number of suppliers in the EMS industry
15. number of facilities of the FSJC' suppliers in Asia
16. number of facilities of the FSJC' suppliers in Europe and North America
17. number of FSJC's qualified suppliers
18. number of FSJC's preferred suppliers
19. Percentage of FSJC's preferred suppliers
20. availability of capacity
21. availability of raw material in Asia
22. availability of raw material in Europe and North America
23. availability of suppliers' labor force
24. capacity of labor force for suppliers utilization of suppliers current capacity
25. availability of tooling
26. leverage of suppliers to purchase raw material
27. suppliers leverage to distribution
28. customer or standard material
29. cost of tools impacts the end solution

Lead Time

30. Lead Time for the tooling
31. Lead Time for suppliers to get the raw material
32. Lead time for manufacturing
33. Transit time for raw material to arrive at the supplier sites
34. Transit time for finished material to arrive at the customer (CLS) site when shipped from the supplier

Capability

35. flexibility of suppliers allocating raw material for FSJC
36. skill level of labor force of suppliers
37. Flexibility of suppliers technology offering
38. Flexibility of Local suppliers
39. Flexibility of global suppliers
40. responsiveness of suppliers
41. suppliers scalability
42. flexibility of supply contracts
43. suppliers quality history
44. suppliers' customer service level
45. on-going service level:
46. inventory accuracy
47. suppliers ramp-up time
48. suppliers categories

Finance

49. foreign currency
50. global labor force rate
51. suppliers financial stability
52. suppliers' cash reserve
53. suppliers' credit
54. debt

Suppliers' supply chain organization

55. ability to manage shortage
56. supplier's proactive to manage their supply chain
57. hardstock
58. efficiency of APS and ERP
59. EDI capability
60. competitiveness of suppliers' logistics organization

Appendix B: Model Documentation

Actual Supplier's Delivery Delay=Supplier's Backlog/Supplier's Order Fulfillment Rate
Units: week

Adjustment for Component WIP = (Desired Component WIP-Supplier WIP)/Components WIP Adjustment Time
Units: units/week

Adjustment for Pre-Assembly Inventory= ("Desired Pre-Assemble Inventory-Pre-Assemble Inventory)/Time to Adjust Pre-Assemble Inventory
Units: units/week

Adjustment for Supplier Pre-Assembly Inventory=(Supplier's Desired Pre-Assembly Inventory-Supplier Pre-Assembly Inventory)/Time to Adjust Supplier Pre-Assembly Inventory
Units: units/week

Adjustment for WIP= (Desired WIP-Work In Process)/Time to Adjust WIP
Units: units/week

Assemble In Process= INTEG (Assemble Rate-Shipping Rate,
Customer Order Initial Value*Minimum Time to Test and Ship)
Units: units

Assemble Rate=Maximum Assemble Start Rate*Fraction of Max Assemble Start
Units: units/week

Average time to Adjust Raw Material Inventory=4
Units: week

Average Time to Allocate Raw Material=1
Units: week

BackLog= INTEG (Order Arriving Rate-Orders Fulfillment Rate,
Customer Order Initial Value*Time to Process and Ship Order)
Units: units

FSJC's Attractiveness=Effect of Delivery Delay on Attractiveness (Delivery Delay/Customers' Expected Delivery Delay)
Units: Dimensionless
Attractiveness is measured between 0 and 2. 0 means unattractive and 2 mean extremely attractive. In the initial equilibrium, we assume the attractive is 1.

FSJC's Market Share=Effect of Attractiveness on Market Share(FSJC's Attractiveness)

Units: Dimensionless

FSJC's Order Fulfillment Performance=Delivery Delay/Customers' Expected Delivery Delay
Units: Dimensionless

Change in Flexibility=IF THEN ELSE(Desired Flexibility<0.5, 0, Max(0,(Desired Flexibility-Supplier's Flexibility to Allocate Raw Material)/Time to Change Flexibility))
Units: 1/week

Change in Priority=(Perceived Priority By Supplier-FSJC's Priority on Supplier's Customers List)/Time to Adjust Priority
Units: Dimensionless

Components WIP Adjustment Time=1
Units: week

Customer Order Initial Value= Initial Value of Market share*Total Industry Demand Base Value
Units: units/week
This Initial Value is a constant, whose purpose is set the initial value for the stock variable in the model. We assume in the initial equilibrium, the total industry demand is flat.

Customers Order Rate=Total Industry Demand* FSJC's Market Share
Units: units/week

Customers' Expected Delivery Delay=2
Units: week

Delivery Delay= BackLog /Orders Fulfillment Rate
Units: week

Desired Component WIP=Supplier's Desired Production Rate*Suppliers Manufacturing Cycle Time
Units: units

Desired Flexibility=Max(0,min(Maximum Flexibility for FSJC,(Supplier Desired Production Start Rate-Initial Production Start Rate for FSJC)/Initial Production Start Rate for FSJC))
Units: Dimensionless

Desired Pre-Assemble Inventory=Desired Pre-Assemble Inventory Coverage*Expected Order Rate
Units: units

"Desired Pre-Assemble Inventory Coverage"=1.5
Units: week

Desired Production Completion Rate=Adjustment for Pre-Assembly Inventory + Expected Order Rate
Units: units/week

Desired Production Start Rate=Desired Production Completion Rate + Adjustment for WIP
Units: units/week

Desired Raw Material Arriving Rate=Raw Material Inventory Adjustment + Total Expected Raw Material Allocation Rate
Units: material/week

Desired Supplier Raw Material Inventory=Average Time to Allocate Raw Material*Total Expected Raw Material Allocation Rate
Units: material

Desired WIP= Manufacturing Cycle Time*Desired Production Completion Rate
Units: units

Effect of Attractiveness on Market Share([(0,0)-(2,0.2)],(0,0.1),(0,0),(0.1,0),(0.15,0.016),(0.2,0.022), (0.3,0.03), (0.4,0.04),(0.5,0.048),(0.6,0.065), (0.7,0.08), (0.8,0.09), (0.9,0.095),(0.96,0.1), (1,0.1),(1.04,0.1),(1.05,0.106), (1.1,0.11),(1.2,0.118),(1.4,0.13),(1.5,0.15),(1.6,0.16),(1.8,0.18),(2,0.2))
Units: Dimensionless

Effect of Delivery Delay on Attractiveness([(0,0)- (4,2)],(0,2),(0.25,1.7),(0.5,1.5), (0.75,1.2),(0.9,1.05), (0.95,1),(1,1),(1.05,1), (1.1,0.95), (0.25,0.9),(1.5,0.75),(1.75,0.63),(1.9,0.61),(1.98165,0.578947),(2.2,0.5),(2.4,0.4),(2.6,0.33),(2.8,0.3),(2.9,0.25),(3,0.25),(4,0))
Units: Dimensionless

Effect of Order Fulfillment on Priority Change([(0,0)-(4,4)],(0,0),(1.2,0),(1.25,0.2),(1.5,0.55),(1.75,0.85),(2,1.25),(2.25,1.65),(2.5,2),(2.75,2.75), (3,3.2),(3.25,3.5),(3.5,3.7),(4,4))
Units: Dimensionless

Expected Order Rate=SMOOTH(Customers Order Rate , Time to Adjust Forecast)
Units: units/week

Exponential Growth Rate=0
Units: 1/week
The exponential growth rate in the input.

Exponential Growth Time=0
Units: week
The time at which the exponential growth in the input begins.

FINAL TIME = 100
Units: week

The final time for the simulation.

Fraction of Max Assemble Start=Table for Assemble Start(Indicated Fraction of Max Assemble Start)
Units: Dimensionless

Fraction of Max Shipping=Table for Max Shipping (Indicated Fraction of Max Shipping)
Units: Dimensionless

Fraction of Supplier Max Assemble= Table for Supplier Max Assemble (Indicated Fraction of Supplier Max Assemble)
Units: Dimensionless

Fraction of Supplier Max Shipping= Table for Supplier Max Shipping (Indicated Fraction of Supplier Max Shipping)
Units: Dimensionless

FSJC's Priority on Supplier's Customers List= INTEG (Change in Priority, Initial Priority)
Units: Dimensionless

Indicated Fraction of Max Assemble Start=min(3,Customers Order Rate/Maximum Assemble Start Rate)
Units: Dimensionless

Indicated Fraction of Max Shipping=min(3, Maximum Shipping/Indicated Shipping from BackLog)
Units: Dimensionless

Indicated Fraction of Supplier Max Assemble=min(3,Desired Production Start Rate/Supplier Maximum Assemble Rate)
Units: Dimensionless

Indicated Fraction of Supplier Max Shipping=min(3,Supplier's Desired Shipping Rate/Supplier's Maximum Shipping Rate)
Units: Dimensionless

Indicated Shipping from BackLog = BackLog /Time to Process and Ship Order
Units: units/week

Initial Priority=Initial Supplier Orders Fulfillment Rate/Supplier Base Sales Rate
Units: Dimensionless

Initial Production Start Rate for FSJC=Customer Order Initial Value
Units: units/week

Initial Supplier Orders Fulfillment Rate=Customer Order Initial Value

Units: units/week

INITIAL TIME = 0
Units: week
The initial time for the simulation.

Initial Value of Market share=0.1
Units: Dimensionless

Input=1+ STEP(Step Height, Step Time) + STEP (Step Height2,Step time2) + STEP(Step Hight3, Step Time 3)+(Pulse Quantity / TIME STEP) * PULSE (Pulse Time, TIME STEP)+ RAMP(Ramp Slope, Ramp Start Time, Ramp End Time)+STEP(1,Exponential Growth Time) *(EXP(Exponential Growth Rate*Time)-1)+ STEP(1,Sine Start Time)*Sine Amplitude* SIN(2*3.14159*Time/Sine Period) + STEP(1,Noise Start Time)* RANDOM NORMAL(-4 ,4 , 0, Noise Standard Deviation , Noise Seed)
Units: Dimensionless
Thc tcst input can be configured to generate a step, pulse, linear ramp, exponential growth, sine wave, and random variation. The initial value of the input is 1 and each test input begins at a particular start time. The magnitudes are expressed as fractions of the initial value.

Manufacturing Cycle Time=2
Units: week

Material Usage Per Unit=5
Units: material/units

Maximum Assemble Start Rate=Pre-Assemble Inventory/Minimum Time to Assemble
Units: units/week

Maximum Flexibility for FSJC=150%
Units: Dimensionless

Maximum Production Rate for FSJC=Raw Material Allocation Rate*Maximum Raw Material Allocation Ratio for FSJC/Material Usage Per Unit
Units: units/week

Maximum Raw Material Allocation Ratio for FSJC= FSJC's Priority on Supplier's Customers List*(1+Supplier's Flexibility to Allocate Raw Material)
Units: Dimensionless

Maximum Raw Material Arriving Rate=75000
Units: material/week

Maximum Shipping=Assemble In Process/Minimum Time to Test and Ship
Units: units/week

Minimum Time to Assemble=1
Units: week
Minimum Order Processing Time includes the minimum assemble time (3-4) days and testing time (1 day), which is roughly one week.

Minimum Time to Test and Ship=2
Units: week

Noise Seed=1000
Units: Dimensionless
Varying the random number seed changes the sequence of realizations for the random variable.

Noise Standard Deviation=0
Units: Dimensionless

Noise Start Time=0
Units: week
The time at which the random noise in the input begins.

Order Arriving Rate=Customers Order Rate
Units: units/week

Orders Fulfillment Rate=Shipping Rate
Units: units/week

Perceived Priority By Supplier=Initial Priority*(1+Step Height)*(1+Step Height2)*(1+Step Hight3)
Units: Dimensionless

"Pre-Assemble Inventory"= INTEG (+Production Rate-Assemble Rate, Customer Order Initial Value*"Desired Pre-Assemble Inventory Coverage")
Units: units

Production Rate=Work In Process/Manufacturing Cycle Time
Units: units/week
Assembling Rate equals the desired Assemble rate, however, the assembling rate cannot exceed the maximum assemble rate, which is determined by stock WIP.

Production Start Rate=Max(0,min(Desired Production Start Rate, Supplier's Order Fulfillment Rate))
Units: units/week
The production start rate is the components arriving rate and constrained to be nonnegative.

Pulse Quantity=0
Units: Dimensionless*week
The quantity added to the input at the pulse time.

Pulse Time=0
Units: week
The time at which the pulse increase in the input occurs.

Ramp End Time=1e+009
Units: week
The end time for the ramp input.

Ramp Slope=0
Units: 1/week
The slope of the linear ramp in the input.

Ramp Start Time=5
Units: week
The time at which the ramp in the input begins.

Raw Material Allocation Rate=DELAY1(Raw Material Purchasing Rate, Average Time to Allocate Raw Material)
Units: material/week

Raw Material Inventory Adjustment=(Desired Supplier Raw Material Inventory-Supplier Raw Material Inventory)/Average time to Adjust Raw Material Inventory
Units: material/week

Raw Material Purchasing Rate=Max(0,min(Maximum Raw Material Arriving Rate, Desired Raw Material Arriving Rate))
Units: material/week
The supplier purchasing rate depends the total market demand for raw material

SAVEPER = TIME STEP
Units: week
The frequency with which output is stored.

Shipping Rate=Fraction of Max Shipping*Maximum Shipping
Units: units/week

Sine Amplitude=0
Units: Dimensionless
The amplitude of the sine wave in the input.

Sine Period=10
Units: week
The period of the sine wave in the input.

Sine Start Time=0

Units: week
The time at which the sine wave fluctuation in the input begins.

Step Height=0.15
Units: Dimensionless [-2,5]
The height of the step increase in the input.

Step Height2= 0.15
Units: Dimensionless

Step Hight3=0.15
Units: Dimensionless

Step Time=5
Units: week
The time at which the step increase in the input occurs.

Step Time 3=11
Units: week

Step time2=8
Units: week

Supplier Assemble In Process= INTEG (Supplier Assemble Rate-Supplier Shipping Rate, Customer Order Initial Value*Supplier Minimum Order Processing Time)
Units: units

Supplier Assemble Rate=Max(0,Supplier Maximum Assemble Rate*Fraction of Supplier Max Assemble)
Units: units/week

Supplier Base Sales Rate=10000
Units: units/week

Supplier Desired Pre-Assembly Coverage=1.5
Units: week

Supplier Desired Production Start Rate= Max(0,Adjustment for Component WIP+Supplier's Desired Production Rate)
Units: units/week

Supplier Maximum Assemble Rate="Supplier Pre-Assembly Inventory"/Supplier Minimum Time to Assemble
Units: units/week

Supplier Minimum Order Processing Time= 2

Units: week

Supplier Minimum Time to Assemble=1
Units: week

"Supplier Pre-Assembly Inventory"= INTEG (+Supplier Production Rate-Supplier Assemble Rate, Initial Production Start Rate for FSJC*"Supplier Desired Pre-Assembly Coverage")
Units: units

Supplier Production Rate=Max(0,DELAY3(Supplier Production Start Rate, Suppliers Manufacturing Cycle Time))
Units: units/week

Supplier Production Start Rate=Max(0,min(Supplier Desired Production Start Rate, Maximum Production Rate for FSJC))
Units: units/week

Supplier Raw Material Inventory= INTEG (+Raw Material Purchasing Rate-Raw Material Allocation Rate, Total Industry Demand Base Value*Material Usage Per Unit*Average Time to Allocate Raw Material)
Units: material

Supplier Shipping Rate=Max(0,Fraction of Supplier Max Shipping * Supplier's Maximum Shipping Rate)
Units: units/week

Supplier Time to Adjust Forecast=1
Units: week

Supplier WIP= INTEG (+Supplier Production Start Rate-Supplier Production Rate,
Customer Order Initial Value*Suppliers Manufacturing Cycle Time)
Units: units

Supplier's Backlog= INTEG (Supplier's Orders Arriving Rate-Supplier's Order Fulfillment Rate,
Customer Order Initial Value*Supplier's Target Delivery Delay)
Units: units

"Supplier's Desired Pre-Assembly Inventory"=Supplier's Expect Order Rate*"Supplier Desired Pre-Assembly Coverage"
Units: units

Supplier's Desired Production Rate= Max(0,"Adjustment for Supplier Pre-Assembly Inventory"+ Supplier's Expect Order Rate)
Units: units/week

Supplier's Desired Shipping Rate=Supplier's Backlog/Supplier's Target Delivery Delay

Units: units/week

Supplier's Expect Order Rate= SMOOTH (Desired Production Start Rate, Supplier Time to Adjust Forecast)
Units: units/week

Supplier's Flexibility to Allocate Raw Material= INTEG (Change in Flexibility, Initial Priority*5)
Units: Dimensionless

Supplier's Maximum Shipping Rate=Supplier Assemble In Process/Supplier Minimum Order Processing Time
Units: units/week

Supplier's Order Fulfillment Rate=Supplier Shipping Rate
Units: units/week

Supplier's Orders Arriving Rate=Desired Production Start Rate
Units: units/week

Supplier's Target Delivery Delay=2
Units: week

Suppliers Manufacturing Cycle Time=2
Units: week

Table for Assemble Start([(0,0)-(3,1)], (0,0), (0.25,0.25), (0.5,0.5),(0.75,0.75), (1,1),(1.25,1), (1.5,1),(1.75,1),(2,1),(2.5,1) ,(3,1))
Units: Dimensionless

Table for Max Shipping([(0,0)-(3,1)],(0,0),(0.25,0.25),(0.5,0.5),(0.75,0.75),(1,1),(1.25,1), (1.5,1),(1.75,1),(2,1),(2.5,1),(3,1))
Units: Dimensionless

Table for Supplier Max Assemble([(0,0)-(3,1)],(0,0), (0.25,0.25),(0.5,0.5), (0.75,0.75),(1,1), (1.25,1), (1.5,1),(1.75,1),(2,1),(2.5,1),(3,1))
Units: Dimensionless

Table for Supplier Max Shipping([(0,0)-(3,1)],(0,0),(0.25,0.25),(0.5,0.5),(0.75,0.75),(1,1), (1.25,1), (1.5,1),(1.75,1),(2,1),(2.5,1),(3,1))
Units: Dimensionless

TIME STEP = 0.125
Units: week
The time step for the simulation.

Time to Adjust Forecast=1

Units: week

Time to Adjust Pre-Assemble Inventory=2
Units: week

Time to Adjust Priority=20
Units: week

Time to Adjust Supplier Pre-Assembly Inventory=1
Units: week

Time to Adjust WIP= 2
Units: week

Time to Change Flexibility=8
Units: week

Time to Process and Ship Order=2
Units: week

Total Expected Raw Material Allocation Rate=Material Usage Per Unit*Total Industry Demand
Units: material/week

Total Industry Demand=Total Industry Demand Base Value*Input
Units: units/week

Total Industry Demand Base Value=10000
Units: units/week

Work In Process= INTEG (+Production Start Rate-Production Rate, Customer Order Initial Value*Manufacturing Cycle Time)
Units: units

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